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ABSTRACT

This document provides the teacher's guide for grade six for the Conceptually Oriented Program in Elementary Science (COPES) science curriculum project. The guide includes an introduction to COPES, instructions for using the guide, instructions for assessment of the student's grade 5 mastery of science concepts, and six science units. Each unit includes from five to seven activities and an assessment. Unit topics include: living things, energy and bonds, copper, degradation of energy, random events, and mechanical systems. Each activity includes a teaching sequence and commentary. (SL)

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COPES

Conceptually Oriented Program in Elementary Science

Teacher's Guide for Grade Six

Preliminary Edition

NEW YORK UNIVERSITY
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"What, precisely, is "thinking?" When at the reception of sense-impressions, memory pictures emerge, this is not yet "thinking." And when such pictures form series, each member of which calls forth another, this too is not yet "thinking." When, however, a certain picture turns up in many such series, then--precisely through such return--it becomes an ordering element for such series, in that it connects series which in themselves are unconnected. Such an element becomes an instrument, a concept. I think that the transition from free association or "dreaming" to thinking is characterized by the more or less dominating role which the "concept" plays in it. It is by no means necessary that a concept must be connected with a sensorily cognizable and reproducible sign (word); but when this is the case thinking becomes by means of that fact communicable...."

--Albert Einstein
quoted in *Einstein* by
Jeremy Bernstein. New York:
The Viking Press, 1973,
p. 172.

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COPES: Background and Acknowledgments

Recognition of the need for a highly structured, sequentially organized K-6 science program grew out of a three-day conference on elementary school science conducted by New York University scientists, psychologists, and educators in 1962. As a result of this conference, Morris H. Shamos, Professor of Physics, and J. Darrell Barnard, Professor of Science Education, developed a plan to produce a conceptually oriented program in elementary science (COPES). With the administrative support of Dean Daniel E. Griffiths, of the School of Education, and Dean George Winchester Stone, Jr., of the Graduate School of Arts and Science, the plan was accepted as an all-University project. The Advisory Committee and Consultants to the project include the following members:

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A two-year pilot study to test the feasibility of a conceptual schemes approach was funded by the United States Office of Education. The success of the pilot study, dealing with one conceptual scheme--the conservation of energy--led to the production of an elementary school science program based upon the five conceptual schemes outlined in the Introduction to this Guide.

The COPES Staff is cited below, along with previous members who have contributed to the Grade 6 materials:

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Many teachers and staff members have been actively involved in testing and teaching the COPES materials. A laboratory school at the University, as well as regular classrooms of cooperating teachers, tested the initial Grade 6 materials.

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Several research studies have been conducted with the COPES materials. Elhannan Keller conducted a study using Minisequence II of Grade 6 in several New York City Public Schools. He devised assessments for that sequence to use for the study, part of his doctoral program at New York University.

Many other teachers, scientists, science educators, and school communities have contributed and still are contributing to the program. Acknowledgment must also be extended to those many children who have worked with COPES materials and who have provided us with immediate and invaluable critiques of the Activities.

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An Introduction to COPES

COPES (Conceptually Oriented Program in Elementary Science) is a science curriculum centered on some of the major conceptual schemes in science. We accept the premise that general education in science is a necessary part of the educational structure, not so much for whatever practical values it may afford as for its pure intellectual stimulation. There is also a growing awareness among the general public of the increasing impact of science and technology on modern civilization. Yet, paradoxically, our society is very poorly informed in science. While many believe that science belongs with those disciplines that traditionally have been regarded as essential to man's cultural enrichment, the average person fails to see it in this light. Whatever the reason, clearly our educational system is at fault. It is probable that past efforts to minimize the intellectual challenge in science curricula have succeeded mainly in distorting the nature of the enterprise in the minds of most school children. By the time these children reach high school, their natural curiosity and interest in science appear to be greatly diminished. Of those that enter college, a great many are actually repelled by science.

Elementary school children, as a whole, are probably the most receptive, the most curious, the most imaginative, and the most cooperative "non-science" students one can find in our educational system. Today, it is apparent that much more can be accomplished at this level than was believed possible in the past. In these formative years, when minds are so receptive to new ideas and before children's patterns of thinking become too crystallized, we think it possible to develop a foundation in science that will remain a permanent part of their intellectual life.

What is the best way to help young children attain a level of understanding and appreciation of science that will serve them through their adult lives? Rather than fill their minds with unrelated facts and details, the COPES approach is to focus their attention on certain of the "big ideas" in science--the broad, inclusive, conceptual schemes in terms of which the scientific community seeks to account for the familiar facts of nature. These central ideas are stressed throughout the program; wherever possible, everything in the curriculum is related to these conceptual schemes. We believe that long after he or she has forgotten the facts of science, a child exposed to such a curriculum may retain some understanding of what is truly important. It should make it clear that science is more than a collection of isolated facts and provide the child with a solid framework on which to construct a personal view of the world of nature. We also believe that having such definite objectives, in the form of conceptual schemes, adds to the pedagogical strength of the curriculum because it provides teachers and students with clearly defined goals, as well as a cohesive picture of science.

THE CONCEPTUAL SCHEMES

Civilized man has always prized bold ideas, whether in art, literature, politics--or science. Throughout history, the great ideas stand out as focal points for new systems of philosophy, new religions, new modes of thought, even new societies. Their counterparts in the sciences play a similar role. The big ideas in science are man's response to the challenge of nature, his way of trying to account for familiar facts in terms of a relatively few basic schemes which help to unify broad ranges of experience. Thus science is not simply a matter of accurate and detailed descriptions of things and events, or of extending our senses by the use of instruments. These are merely steps to a much larger objective: the invention of models (theories) that form the bases for all explanation in science. Such unifying ideas as the kinetic-molecular theory, the statistical view of the universe, the conservation principles, the quantum theory, the gene theory of heredity, etc., are the kinds of fundamental schemes to which scientists instinctively turn when faced with new problems. They represent the pinnacle of explanation in science, the product of man's creative imagination--and should be classed among the greatest of his intellectual achievements.

While they may differ greatly in subject matter within the broad field of science, these conceptual schemes have in common that they are not susceptible to direct experimental verification. Thus, the assumption that matter is composed of small, discrete particles--atoms or molecules--which is basic to the kinetic-molecular theory, is obviously not subject to proof of the kind that might be considered "direct." The same is true of all major conceptual schemes; to scientists they are essentially "articles of faith." Our confidence in them rests upon the degree to which they help us to account for our experiences with nature in an intellectually satisfying fashion. And the wider their range of application, the stronger is our belief in their validity. This is not to say that conceptual schemes are infallible; they are, after all, subject to almost the same uncertainties as any other of man's ideas. But those that persist after being subjected to the test of time, including repeated challenges and refinements by competent critics, become the foundations of science.

Five such conceptual schemes form the nucleus of the COPES curriculum: 1. The Structural Units of the Universe; 2. Interaction and Change; 3. The Conservation of Energy; 4. The Degradation of Energy; 5. The Statistical View of Nature. These schemes were selected because they include most of what is fundamental in science and because they provide the basis for a logical, sequential development of skills and concepts through the elementary grades. It may be noted that the last three schemes are new to the elementary school. They have been taught, if at all, only in the secondary schools and colleges. Nevertheless, because of their great importance in contemporary science, and a conviction that even such seemingly sophisticated topics can be made meaningful to elementary school children, they are included in COPES.

Following are brief descriptions of each of the conceptual schemes from a scientific point of view. How COPES deals with them is described in greater detail in introductions to each grade level and sequence of Activities.

1. The Structural Units of the Universe

The notion that the universe is made up of various kinds of discrete units of matter is central to the formal pursuit of science. Whether they be the smallest subnuclear particles or the largest stars, whether a single living cell or a complex organism, it is the discreteness of matter that makes it feasible to study nature--to classify its structural units and establish a hierarchy among them. Atoms, molecules, crystals, cells, organisms, plants, animals, planets, stars, etc.--these are the structural forms in which matter is found. The more complex forms, or higher levels of organization, exhibit properties that are generally more than the simple sum of their parts. The structural units with which students have any direct experience, that is, large-scale matter, are composed of smaller units, and these, in turn, of still smaller units. As for the fundamental "building blocks" of matter, for the purpose of the COPES program these are taken to be atoms or, as more commonly encountered in nature, molecules.

While the idea that matter is made up of discrete parts is obviously an important one, a corollary is perhaps equally important: This holds that nature is essentially simple--that in spite of the great diversity we observe, the number of truly different "building blocks" is reasonably small. The number of different molecules (compounds) is huge, but all are made of combinations of two or more atoms. There are only about one hundred different kinds of atoms (elements) found in nature, but even these exhibit certain similarities that permit grouping them into still fewer major categories (e.g., the eight different "families" of the Periodic Table). It is this simplicity that permits us to seek out the order in nature and understand it. Think how impossible this task would be were it not for the fact that we are able to reduce our observations to relatively few *totally* different experiences. Corresponding order is found in the life sciences. The basic reason for classifying things--for seeking similarities among apparently diverse plants and animals--is to reduce the total number of *different* living things to manageable proportions. Think how difficult the life sciences would be if no two plants, or no two animals, had similar characteristics.

2. Interaction and Change

Taken as a whole, the universe is constantly changing. This is evident at most levels of organization: stars, planets, geological formations, living things, etc., all change with time in perceptible ways. Some changes are readily observable, which means that they occur in relatively short periods of time. Certain chemical and nuclear reactions are examples of rapid changes. Others, such as most evolutionary or geological changes involving very long periods of time, are not as evident and must be inferred from indirect evidence rather than from direct observation. Thus the rate at which a given change occurs is a critical factor in detecting this change and assessing its magnitude and import.

Changes occur because of interactions among the structural units of matter, with the result that either the properties or arrangement of the units may be altered. Interactions among units of matter take place through fields of force, of which several basically different types can be distinguished. Only two of these, gravity and electromagnetism (electric and magnetic forces), are normally experienced by the average individual. In fact, the electric force alone is sufficient to account for most of our experiences, including practically all chemical and biological changes. The weakest force (gravitational) and the strongest (nuclear) play particularly interesting roles in effecting changes in the universe. The former is significant only for the largest structural units--planets, stars, etc.--while the latter applies only to the smallest, subnuclear particles.

No change occurs without an interaction--either between units of matter or between matter and energy. Thus the concept of force as the "agent" of change plays a central role in science and in understanding the evolving universe.

3. The Conservation of Energy

As one contemplates the concept of a changing universe, it is comforting to find some properties of the universe that appear to be invariant. Such invariant properties are said to be "conserved," and the statements describing them are generally referred to as "conservation laws."

The most fundamental of these laws are *conservation of electric charge* and *conservation of energy*. The latter is of special interest because it is so basic to all of science. In fact, the concept of energy itself became central to all of science, largely because of the conservation idea. Conservation of matter, if thought of as conservation of mass, while a useful concept in ordinary, low-energy phenomena, is not valid for high-energy interactions. Instead, the principle of conservation of energy has been broadened to include mass as a form of energy, leading to the conservation of matter-energy.

The notion that the total amount of matter and energy in the universe remains constant is obviously a powerful conceptual idea, perhaps the most useful guiding principle in all of science. The more limited idea of conservation of energy alone, while not so inclusive, is found to hold so well for the low-energy interactions normally encountered by children (e.g., in energy conversions) as to constitute a highly significant conceptual scheme at the level to which the COPES program is addressed.

4. The Degradation of Energy

One cannot fully develop the idea of energy conservation in a meaningful way without also calling attention to the *direction* of energy changes, as embodied in the corollary conceptual scheme, degradation of energy.

Natural events tend to have a unidirectional character. That is, changes occur in such a way as to bring the universe closer to a final state in which it will have lost the ability to do any useful work. Thus, in the conversion of energy from one form to another, while the principle of energy conservation applies, part of the energy appears in a form that cannot be fully harnessed to do mechanical work. This form is heat energy, by which is meant the kinetic energy of the assumed random motion of particles of matter.

The idea of particles moving at random is central to the kinetic-molecular theory, which has proved to be an effective model for understanding gases, as well as the concepts of heat, temperature, and the states of matter. In this sense degradation of energy means that every change in the universe occurs in such a way as to result in greater randomness--that is, matter tends to spread out or become less organized and energy tends to distribute itself more widely.

In more formal terms, the idea that changes occur in this fashion is expressed as the *second law of thermodynamics*.

Thus, heat flows from a warmer to a colder body, but the reverse is not observed unless energy is supplied from an external source. Similarly, it is easy to fill a large container with gas (molecules) by releasing a small amount of gas into it--the gas "spreads out" to fill the container. The reverse is not so easy. Compressing gas from a large container into a smaller one requires that external work be done on it. The same general idea applies to all changes that appear to result in higher states of organization, even to those in living systems. While the organism itself may become more ordered, it does so only at the expense of its environment, which becomes more disordered. The net result is an overall trend toward disorder, meaning that the total energy is degraded.

5. The Statistical View of Nature

The modern view is that natural events can be predicted only on a statistical basis. Most of our experiences with nature involve large numbers, with the result that, on the whole, nature appears regular and predictable. Even the smallest sample of matter with which one normally comes into contact contains huge numbers of atoms or molecules, so large that one can readily predict the *average* behavior of the sample. This is somewhat analagous to a game of chance where, given a large number of events, the overall outcome can be reliably predicted--even though the result of a single event cannot be forecast. In fact, the same mathematical laws of probability that apply to games of chance appear to be successful in helping one predict the statistical behavior of natural phenomena.

When one studies individual or small numbers of events, the random character of natural phenomena becomes evident. Radioactivity is one such phenomenon where behavior can be predicted only on a statistical basis. Another example is the transmission of genetic characteristics to successive generations of living things, as described by the Mendelian laws. Still another is the Brownian motion of small, microscopic particles, which have an erratic, unpredictable motion. Examples are limited because randomness is apparent only when dealing with small numbers, which one does not often encounter in nature.

Yet the idea that on a submicroscopic level all phenomena are random, and that nature is predictable only by the play of large numbers, is obviously a basic and important conceptual scheme. The challenge is to convince children that one can reasonably generalize to this conclusion from the few concrete examples that are available--to convince them, for instance, that while the motion of individual molecules of a gas is perfectly random, the overall behavior of a large collection of molecules, like that involved in the diffusion of cooking odors through a house, is entirely predictable.

THE METHODOLOGY OF SCIENCE

Such are the "big ideas" with which COPES is concerned. There is more to them than appears here, of course, and elaborations of each of the schemes will be found at various points throughout the curriculum. There is also more to the "conduct" of science than may be apparent in this approach. What might be called the *methodology of science*, by which we mean both scientific procedure and the attitudes one must bring to it, is an essential part of scientific inquiry.

There is a popular misconception that in the practice of science one proceeds in an orderly, systematic, prescribed fashion. The term "scientific method" is often used to describe this, as though all that is needed for scientific discovery is to follow a particular set of rules. The term is unfortunate because it implies a fixed routine that one rarely, if ever, finds in practice. There is no one "scientific method." Instead, there are certain processes that one can identify as being common to all scientific inquiry. These include such steps as observation, measurement, experiment, formulation of laws, and the creation of theories.

Since one can hardly expect students to formulate basic laws and theories, science process takes on a somewhat different connotation in the classroom. Here, the emphasis is generally placed upon careful observation and measurement, the formulation of "hypotheses" by the students, and the design of experiments to test their hypotheses. The latter might be thought of as "student theories."

Learning to "observe," rather than merely to "see," to make careful measurements, and to report results accurately and concisely are skills that should stand one in good stead in all walks of life. So, too, should the habit of logical thought, the value of which is very evident in science and mathematics. As for experiment, asking the *proper* questions of nature is both an art and a skill--and, in the final analysis, is the only way of testing the validity of ideas about nature.

All these considerations, plus a fundamental belief that nature is orderly and that its behavior can be understood through scientific study, comprise the methodology of science.

Using the COPES Teacher's Guide

COPES is a spirally constructed elementary science curriculum that proceeds from Kindergarten through Grade 6, by a progressively sophisticated series of learning experiences, to an understanding of the five major conceptual schemes outlined in the Introduction. In the COPES Teacher's Guides, the learning experiences to be developed are presented as sequences of teaching Activities.

THE MINISEQUENCES

The pre-sequence of COPES Activities is designed for young children and is presented in two volumes--the Kindergarten-Grade One and Grade Two Teacher's Guides. The main sequence of teaching Activities for Grades 3 through 6 is divided into a series of shorter sequences, each of which is called a Minisequence. The teaching Activities in a Minisequence focus upon a set of closely related concepts supporting one or more of the conceptual schemes. Activities have been serially arranged, as have the Minisequences within each grade.

The titles of the Minisequences and teaching Activities for which this final Teacher's Guide has been prepared are listed in the Contents on pages vii and viii. In the Guide, each Minisequence is preceded by an introduction which summarizes its relevant features and conceptual development. You can obtain a good overview of the Activities in this Guide by reading the introductions to the various Minisequences.

Assessment materials have been prepared for each Minisequence to assess the concepts presumed to be developed and to aid children in attaining mastery of them. The assessments for the sequences in Grade 6 appear in a separate Assessment Kit booklet.

THE ACTIVITIES

Within each Minisequence, Activities are arranged and numbered in the order in which they should be taught. Although the title of each Activity indicates something of its nature, the introductory paragraph which follows states its objectives and describes briefly what it includes. Each introduction may also explain how the Activity is related to others in the Minisequence. As you will note, the introductory statement is followed by a list of materials and equipment, suggestions about how to prepare to teach the Activity, and an indication of the approximate amount of time that will be needed to complete the Activity.

Suggestions for step-by-step teaching procedures, including questions that might be raised with the children, are presented in the main body of the Activity in the left-hand columns entitled TEACHING SEQUENCE. Practical hints, explanations of the science content, and alternative teaching suggestions are included in the right-hand columns entitled COMMENTARY. The teaching suggestions are somewhat detailed. During your first time through the Activities, you may wish to follow the suggestions rather closely. After that you may prefer to modify the procedures in ways that are more in keeping with your own teaching style.

At the end of some Activities, there is a final section called EXTENDED EXPERIENCES. These sections suggest ways in which the children can obtain further practice with the skills or ideas in the Activity or ways in which their understanding of the underlying concepts can be enriched. The Extended Experiences are meant to provide opportunities for particular children to go beyond the specific activities outlined in the Teaching Sequence.

INVOLVEMENT OF CHILDREN

A fundamental commitment underlying the development of all COPES teaching materials is that the children must become intellectually involved in each learning activity. These materials will help you to encourage such involvement by creating learning situations that, from the child's point of view, are incomplete. You will then lead the child to produce an idea that tends to complete the situation. In psychological terms, you will be helping the child to create a meaningful entity, a *gestalt*, from the observations he or she makes during each Activity. To the extent that the child contributes to this creation, by finding necessary data or by evolving an explanatory idea, the gestalt becomes *his or her* concept to label, to remember, and to use in further explorations.

In a COPES Activity, there are objects and ideas about the objects. Both objects and ideas may be arranged in various ways. You and the child may evaluate the implications of different arrangements with regard to how complete each appears to be.

The children's interest in explaining their observations of different arrangements can be used to encourage them to arrange their knowledge systematically and to search for information that appears to be lacking.

The Activities presented in each Minisequence are examples of how specific parts of the environment can be arranged. The Activities lead the children to develop new concepts in order to explain what they observe. In the overall COPES program, the concepts evolving from the Minisequences at successive grade levels are gradually blended into more widely applicable concepts. That collection of concepts, in turn, is part of what is called "Science."

To be successful in teaching science, it is desirable to help children develop the point of view that science is a cooperative venture. You should attempt to use whatever techniques seem appropriate to get children directly involved and working together in planning each Activity, in assembling materials and equipment, in collecting, organizing, and interpreting data, and, finally, in arriving at whatever conclusions appear to be reasonable.

To assist the children in performing these tasks, Worksheets are included whenever appropriate. These must be duplicated in sufficient quantities for each child to have his or her own. Worksheets are used in recording data and in applying the mathematical skills required to interpret the data. Through experience, the children should see that putting information on paper makes it unnecessary for them to remember numbers when they want to compare one result with another and that the systematic arrangement of data makes explaining the results easier. In short, the Worksheets provide a place to store information and facilitate its interpretation.

Worksheets are bound into the Guide at the places where they are to be used. In this condition they cannot be easily reproduced. Therefore a separate section containing duplicate copies of all Worksheets is included at the end of the Guide. These single copies are to be torn out along the binding of the Guide, as needed, and used for reproducing multiple copies for the children. Thus it is essential that you have facilities for reproducing copies of these materials.

The materials used by the children, for the most part, are familiar. Some equipment, such as test tubes, magnifiers, and thermometers, may be new to them. If so, allow the children time to play with such items before they begin to use them. If this is not done, their attention will be divided between their desire to explore the new equipment and becoming involved in using it in the Activity. You will notice that the materials and equipment to be used by the children in a particular Activity are not simply handed out at the beginning. Instead they are distributed when the children perceive a need for them, often as a result of discussions where problems or questions are raised requiring the equipment to investigate them.

From time to time, materials and equipment with which the children have been working may be left in a place where they can continue to work with them during their free time. This opportunity helps not only to sustain interest but to reinforce skills, wherever additional practice would be useful. Finally, it is desirable to use materials at home and out-of-doors whenever possible. Children should not have their conception of science restricted to what happens during the "science period" in the classroom.

In order to get as many children as possible directly involved in each Activity, it is suggested that they work individually where distribution of materials and supervision are not too difficult. In those Activities where teamwork is not only feasible but desirable, it is suggested that they work in small groups of two to five children. In only very few Activities, where the techniques are too difficult and/or possibly dangerous for the children to manage, will the teacher demonstrate.

Suggestions are given for initiating each Activity. This is generally done by suggesting ways in which the new Activity builds upon the previous one(s). Regardless of how it is done, children should be helped to recognize the reasons for getting involved. You should not feel constrained to limit your approaches to those suggested--you know the children and the kinds of approaches that will have the greatest appeal to them.

PREPARATION OF MATERIALS AND EQUIPMENT

The teacher holds the key to the success of any science program, and COPES is no exception in this regard. If anything, the teacher must assume a more critical role then in many elementary science programs. There are no textbooks for the children. All learning Activities must be teacher-initiated and judiciously directed.

From a child's point of view, COPES is essentially a "do-it-yourself" science program. This means that the materials and equipment must be available, or there will be no science learning. If there is more than one teacher for each grade in your school, the task of collecting materials can be shared. This will considerably reduce the preparation time required by any one of you. Children and paraprofessionals may also assist you in bringing the materials together. (Whenever some advance preparation must be made, it is detailed for the teacher.) Getting organized for science teaching takes time; however, it is one of the imperatives of effective teaching in COPES.

One of the advantages of COPES is that it is not necessary to obtain complicated--and expensive--laboratory kits in order to teach the program. As you will observe from an examination of the lists in the Activities, and the cumulative listing at the end of this Guide, the materials and equipment required are relatively simple and, for the most part, are readily available locally. Some of the equipment, such as children's scissors, may already be available in your school; a few items may have to be ordered from one of the scientific supply companies. Insofar as possible, the same materials and equipment are used repeatedly throughout each Guide and from grade to grade. This is done to reduce the need for a wide variety of materials and equipment. For convenience, the quantity of items indicated in the list with each Activity is based on the assumption that there are 30 students in the class. You will need to obtain only enough for the actual number of children in your group. Quantitative specifications of materials are given in both the English and Metric systems. However the Metric system is used with the children throughout the COPES curriculum, whenever measurements are made.

TEACHING TIME

The recommended number of hours that the children will need to complete the work is given for each Activity. The time to be allocated is given in hours, rather than class sessions, because the duration of the latter varies so much from school to school, and even from class to class. It is usually reported as a range of hours rather than a specific number. You may find that some Activities will be completed in less time than recommended, whereas others may take longer. Avoid rushing the children; on the other hand, avoid extending work beyond the time that is obviously suitable. You must be the judge regarding the optimum time to allocate for each Activity.

Most Activities take between half an hour and two hours. The children's attention span must be taken into account in determining how the longer Activities will be broken up. Logical breaking points are at the end of the numbered Sections in the TEACHING SEQUENCE for each Activity.

PRODUCTIVE DISCUSSIONS

Discussions of children's observations are frequently used in leading them to the idea or concept for which the observations were planned. However, as you know, the best-intentioned discussions do not always turn out as planned. When this happens, teachers often resort to asking clue questions to help children guess the teacher--desired response. Such a technique, born out of desperation, usually results in a trial-and-error guessing game rather than in an intellectual experience.

In order to initiate and sustain effective discussions among the children, it is necessary to ask productive questions. Such questions stimulate the intellectual processes of children and assist them in using their observations to arrive at the conceptual goals. In the TEACHING SEQUENCE, questions are suggested that may help you direct discussions toward these ends. The children should be given adequate time to handle the questions. There is often as much silent time in an effective discussion as there is talking time.

REVIEW AND REUSE OF SKILLS AND CONCEPTS

It cannot be assumed that a concept or a skill is learned the first time it is introduced. For instance, the concept of magnetic force as the push or pull of one magnet on another is one that is learned by repeated observation of the behavior of magnets in a number of different situations. Skill in using a thermometer comes after repeated experiences in using thermometers to measure the temperature of a variety of substances. Concepts such as properties, and skills such as classifying, are introduced in the kindergarten teaching materials and reintroduced in practically every subsequent grade level. Throughout the COPES program there is constant review and reuse of important skills and concepts.

The Grade 6 Assessments

The primary theme of the COPES curriculum is that experience with the ideas underlying common phenomena can lead the child to conceptualize the fundamental and pervasive schemes of modern science. Throughout the Activities, emphasis is placed on concepts and relationships rather than on specific phenomena, or "facts," and so it is in the Assessments, which are available in a separate Grade 6 Assessment Booklet. The Assessments have been prepared at two levels: *Screening Assessments,* designed for group administration to ascertain which children have attained mastery of a given concept; and *Individual Assessments,* designed for administration to a single child or small group. In the Booklet, Screening Assessments are presented for each Minisequence while the Individual Assessments are included in the Scoring Guide section. The Individual Assessments have been constructed to help the teacher focus instruction on those areas in which children need additional help.

USING THE ASSESSMENT RESULTS

It is our intent that the Assessments not be used to differentiate one child from another, e.g., as a basis for "grading." Two major uses of the Assessment responses are intended: First, the teacher may use quantification of the responses as evidence for a decision regarding the mastery of concepts by the group as a whole. The teacher must be the major decision-maker in this context. Second, the Assessments should be used as components in the essential feedback you provide the child as he or she strives for mastery of the concepts.

Minisequence I
Interactions of Living Things with the Environment

Living things interact in many ways with other living things and with the non-living, physical components of their environment.

In a specific population of living things, individuals interact with other individuals and with the population as a whole. In a wider community of living things, one population interacts with another population and with the community as a whole. In turn, one community of living things may interact with another community as well as with the larger, more complex global community. The various levels at which living things interact with other living things are determined by the parts and wholes of which they are composed.

The interaction of living things with the physical components of their environment are inherent within life processes. Living things must interact with air, water, and other forms of matter in order to sustain and propagate themselves. Green plants, the ultimate food producers for all living things, interact with light energy in order to obtain the energy to carry on food-synthesizing processes.

At any one time living things are interacting with more than one component of their physical environment. For example, a green plant not only interacts with light but simultaneously with water, heat energy, air, and different kinds of matter in the substrate within which it is growing. In fact it is difficult to isolate any one part of the total environment of a living thing to study its effect upon the development of that living thing. However, through controlled experimentation, much has been learned about the effect of specific components of the physical environment and how each may become a limiting factor in the development of living things.

When it is stated that living things interact with their environment, it is implied that the environment acts upon them and they, in turn, act upon the environment. In other words both they and the environment are changed as a result of the interaction. For example, most living things must have free oxygen to carry on essential life processes. They obtain the oxygen from air or water. As oxygen is used by living things, they, in turn, give off carbon dioxide to the air or the water surrounding them. Thus the environment is changed by the removal of some of the oxygen and the production of more carbon dioxide. If this process were to continue, it would not be long before there would be insufficient free oxygen to sustain life. However, another interaction is taking place at the same time which prevents such a catastrophe. In certain phases of the food-making processes, green plants take up carbon dioxide and use it to make compounds called carbohydrates. In this process oxygen is given off as a by-product. Unless other conditions, such as fuel-burning processes, increase excessively the concentration of carbon dioxide in the atmosphere, the interaction of green plants with the environment maintains a balance between free oxygen and carbon dioxide that is optimal for living things.

The nitrogen cycle is another example of a reciprocal relationship between living things and their environment. Nitrogen is needed to build life-sustaining substances called proteins. Ultimately living things obtain nitrogen from green plants that, in turn, have obtained it from compounds in the soil or water called nitrates. If the process of nitrogen-use continued in one direction only, i.e. from soil to living things, eventually the nitrogen supply in soil and water would become too low to sustain life. However, again this does not happen because waste materials containing nitrogen compounds are given off living things. Furthermore, when they die, the nitrogen compounds in their bodies are returned to soil or water. In soil and water the nitrogen compounds again become available to plants for recycling through other living things.

In numerous cycles of interaction such as those just described, living things obtain life-sustaining materials from their environment. However, after the materials are used they are eventually returned to the environment where they are again made availalbe for recycling.

This Minisequence has been prepared to give children classroom experiences with interactions such as those referred to above and to suggest a variety of out-of-door investigations as extended examples of them. It is introduced with an investigation of soil in Activity 1. The investigation includes consideration of the interaction processes by which soil is formed, the complexity and variability of its composition, one of the ways it interacts with water, and the comparative plant-growth-producing qualities of two different types of soils. In the next two Activities it is demonstrated that one way in which plants and animals change their environment is to release carbon dioxide into it. However, green plants, during their food-making periods, remove some of the carbon dioxide and replace it with oxygen. It is then shown that plants also change their environment by adding water vapor to it. However, such changes, in turn, have an effect upon plants. Finally, samples of woodland litter are examined for evidence of interactions between a population of small animals and other components of the litter environment.

In phenomena as complex as the interactions of living things with their environment, all five conceptual schemes apply. However, *The Structural Units of the Universe*, and *Interaction and Change* are basic, and therefore more readily demonstrated.

The concepts being developed in this Minisequence are:

1. Soil is formed by the interaction of rocks with both living and nonliving components of the environment.

2. As a consequence of their composition, topsoil and subsoil exhibit different interaction properties with water and growing plants.

3. One way in which organisms may interact with thier environment is to release carbon dioxide.

4. There are a number of factors that affect the rate at which plants release water vapor to their environment.

5. Living things react to changes in their environment.

Activity 1 Interactions Between Plants and Soil

Living things ultimately depend upon green plants for life-sustaining food. Green plants, in turn, are dependent upon a water environment or a soil environment for many of the raw materials needed to maintain themselves and their food-making processes. Because of the great abundance of green plants in ocean water and the large amount of the earth's surface which oceans cover, great quantities of food are available in the ocean. However, people have not yet begun to use the ocean, as they have the land, to supply themselves with food. We are presently highly dependent upon the soil for many of the essential materials that go into the production of our food. Soil is an extremely complicated system with a number of interacting components.

The idea that soil is not a single substance, but made up of many parts of different sizes, shapes, and kinds was introduced in Grade 3, Minisequence 1, Activity 2. In the present Activity the understanding of soil is extended to include the idea that there are different types of soils, as determined by where they are found and the properties which they exhibit. In addition, soil varies in its growth-producing potential.

MATERIALS AND EQUIPMENT:

16	coffee cans, 1 pound size, with plastic covers
8	quarts (liters) of topsoil
8	quarts (liters) of subsoil
1	potted plant, such as a geranium
1-8	balances, e.g., Ohaus Student Balance Model No. 1200, (one for each group would be desirable)
1-8	sprinkler bulbs, such as those used in sprinkling clothes
1	pkg corn seeds, 1-oz
3	thermometers, -20°C to 50°C
	supply of paper towels

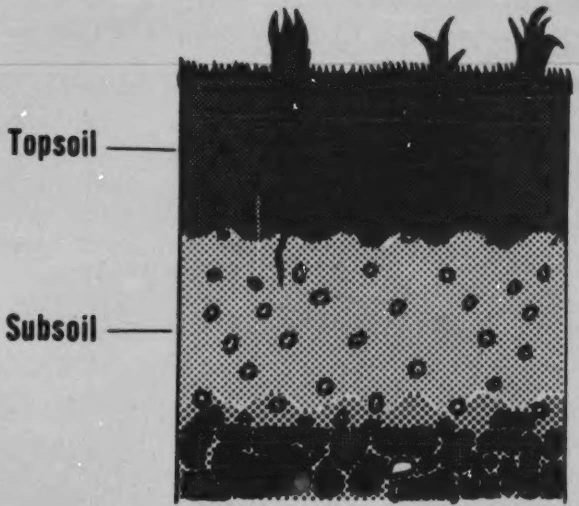
For each group of 4 children:

1	sheet of newspaper, at least 2 pages

3	cups, polyfoam, 8-oz (240-ml)
1	cup, plastic or waxed paper, 1-oz (30-ml), unit measure
4	magnifying glasses
1	screen, 18-in. mesh, 6-in. by 6-in. (15 cm by 15 cm), obtainable from hardware stores
1	screen, 10-in. mesh, 6-in. by 6-in. (15 cm by 15 cm)
1	screen, 4-in. mesh, 6-in. by 6-in. (15 cm by 15 cm)
8	sheets of plain white paper
1	tall, narrow, glass jar or bottle, with lid, for instance, an olive jar
2	aluminum pans, 4-in. (10-cm) in diameter
1	pair of scissors
1	Worksheet I-1

PREPARATION FOR TEACHING:

Most soils are produced from rocky materials at the surface of the earth. Exposed rocks are continually, but slowly, being broken up by wind, rain, heat, and crustlike plants that grow upon them. As rocks are slowly crumbled into smaller particles, other kinds of plants can grow in the developing soil. Eventually many kinds of animals find this material a suitable place to live also. When these plants and animals die, their remains become mixed with the rocky material. In this way, organic material is added to the developing soil. As the process goes on over thousands of years, the uppermost soil becomes the most fertile. It is called *topsoil*.

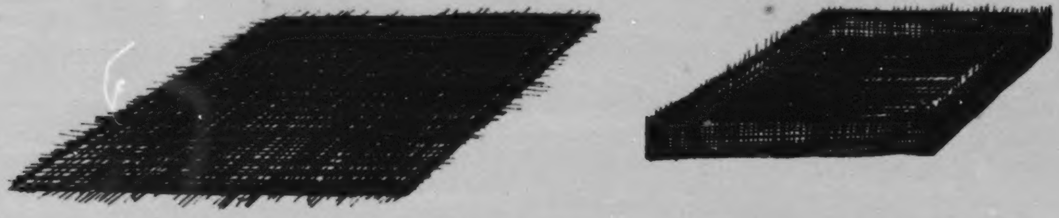


By the processes described above, it takes about 1000 years to produce one inch of good topsoil. As shown in the diagram, the layer of soil beneath the topsoil is called *subsoil*. Subsoil is younger and less fertile than topsoil. About the only place where original topsoil can be found today is on land that has not been markedly disturbed by natural forces such as earthquakes, floods, and glaciers or by human activities such as farming, mining, and different kinds of construction.

In this Activity the properties of topsoil and subsoil are to be compared. It is therefore necessary that samples of each of the two types of soil be obtained. The best places to find them are where a deep hole has recently been dug into the earth to construct the foundation for a building or places where wide cuts in hills have recently been dug for a new highway. Along the banks of such places it is usually possible to locate the different layers of soil shown in the diagram.

After locating such a place, obtain permission, if necessary, to remove some of the soil from each layer. At a time when the soil is relatively moist from recent rains, take a group of at least four children to the location. It would be preferable to take all the children, with each group of four collecting a sample of topsoil and subsoil. Have the children remove eight samples of topsoil and eight samples of subsoil from corresponding layers. Each sample should include at least one quart of soil. All samples should be put into coffee cans and labeled as either topsoil or subsoil. The label should also carry the location from which it was obtained.

Ask several children to help you turn up the edges on all of the screens to prevent the soil from falling off while sieving.



Arrange the Materials and Equipment at convenient pick-up stations in the room so that the children can help themselves.

You may want to plant several corn seeds in a pot of soil before beginning this Activity. (See Commentary on p. 27.)

ALLOCATION OF TIME:

This Activity will take about 4 hours of class time; however, the corn-growing experiment in Part C will take at least 3 weeks of periodic observation and record keeping.

PART A

TEACHING SEQUENCE	COMMENTARY
	In this Part of the Activity children will compare their samples of topsoil and subsoil with respect to: components, as they can be determined visually, and relative amounts of particles of different sizes, as determined by sieving and sedimentation.
1. Introduce this Activity with a discussion of soils based upon the following questions:	The children should be encouraged to use the observations made and conversations held during their sample-collecting trip as background for this discussion.
• From what do most soils originate?	Rocky material.
• How would you expect topsoil and subsoil to be alike?	Both are made of particles of rocky materials--crumbly mixture, brown in color, etc.
• How would you expect topsoil and subsoil to be different?	The children may suggest that subsoil will have more large particles, such as large rocks. Because it has more organic material in it, topsoil would probably be a different color. However, the children may not realize that topsoil has more organic material in it. Let them freely suggest possible differences.
Divide the class into groups of 4. Give each group a full double-page sheet of newspaper and ask them to spread it over their work area. Have each group obtain the following materials: 1 8-oz polyfoam cup 1 1-oz cup 1 magnifying glass for each child	Groups of 4 work well in this Activity.

TEACHING SEQUENCE	COMMENTARY
1 set of 3 screens 1 container of topsoil 1 container of subsoil	
Ask the children to base all of their observations upon a one-cup (8-oz) sample of each soil. Suggest that they keep this in mind when taking soil to use. They should try not to waste it.	The remaining soil in each original sample is to be used in subsequent parts of this Activity.
Pour a one-cup sample of each type of soil onto the sheet of newspaper.	The two samples should be arranged on the newspaper so that they are clearly separated from each other.
• Are the two types of soil the same color?	No, the topsoil should be darker in color. The soil will vary from light yellow to dark brown, but regardless, the topsoil and subsoil will differ in color. This is accounted for by the presence of more decomposed plant and animal material in the topsoil.
Ask the children to put their noses directly over each sample and sniff it.	
• How do their odors differ?	The topsoil should have more the odor of decomposed organic material--an "earthy" smell.
Suggest that they examine their soil samples for organic material.	
• What are organic materials?	Organic material includes both plant and animal material, whether living or dead. Plant material may consist of pieces of roots, stems, and leaves. Animals may consist of insects, worms, spiders, mites, and ticks.
Ask them to spread out each sample of soil and pick out the organic material from each	One-half of each group should work on the topsoil and the other half on the subsoil.

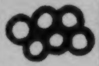
TEACHING SEQUENCE	COMMENTARY
separately. Encourage them to use their magnifying glasses to locate small bits of it and then compare the amount and variety of organic material in the two samples.	
After they have picked out the organic material, remind the children that each group was examining a sample (1 cup) from a sample (1 quart) of soil taken from a large area. Therefore, it would be quite proper for all of the groups to combine their collections of organic material from topsoil and combine their collections of organic material from the subsoil in order to compare the total amount of organic material from as many cups of each soil as were examined.	It is suggested that this be done in order to emphasize the concept that samples are parts of the total population and that the larger the sample, the more sure one can be that it is representative of the total population.
Have them combine the organic material found in each type of soil and estimate its volume by using the 1-oz unit measure cup.	The amount of organic material from each one-cup sample will be relatively small. However, by putting it together, it will be possible to make a reasonable estimate of its amount.
Now have them compare the amount of organic material in topsoil with that in subsoil.	They should find somewhat more organic material in topsoil.
2. Next, have the children compare the size of particles in the remainder of each of their samples of soil. First call their attention to the three screens and have them note how the meshes of the screens are different.	You may want to label the screens in a graduated way, such as 1 (largest mesh), 2, and 3. The label can be taped on a turned up edge.
• How could you use the screens to compare the sizes of particles in the two types of soil?	This may be done by first passing each sample of soil through the screen with the largest mesh. The particles that remain on the screen should then be set aside on a piece

TEACHING SEQUENCE	COMMENTARY
	of paper in order to compare later the relative amount of large particles in each type of soil. The portion of the sample that passes through the large-mesh screen should be sieved through the screen with the next smaller mesh. The same procedure as above should be followed for setting aside the particles that did not pass through the second screen. The remaining soil should be sieved through the screen with the smallest mesh and the particles from each sample that do not go through it should again be set aside for later comparison. This procedure will result in the separation of four different size particles for each type of soil:
After the children have divided the samples of each type of soil into four parts based upon the relative sizes of particles which it contains, ask them to use a magnifying glass to examine some of the particles of soil that passed through the screen with the smallest mesh.	1. larger than mesh holes in screen 1 2. larger than mesh holes in screen 2 3. larger than mesh holes in screen 3 4. smaller than mesh holes in screen 3 The amounts of each size may be compared by weight or by using the 1-oz cups (unit measure) to determine their relative volumes.
• Are the particles all the same size?	No, they are not.
• How can this part of the sample be further divided into portions with particles of about the same size?	Someone may suggest that smaller mesh screens be used.
Since no screens having a smaller mesh are available, suggest a sedimentation or settling technique. Show them a jar of water and ask how it	

TEACHING SEQUENCE	COMMENTARY
might be used to bring about further separation. Then distribute a narrow glass jar and lid to each group. The children should put the soil that passed through even the finest screen into the jar, add water, fasten the lid, shake it vigorously, and then set it aside for a day or two. They should use at least three times as much water in the jar as there is soil.	Let the children discuss their ideas before you proceed.
	Within one day most of the soil will have settled to the bottom of the jar. The largest particles will settle out first and the smaller ones last. After two days, all of the material may still not have settled out of the water. Some fine organic material may be left floating on top. Also, the water may be cloudy, indicating that there were some particles in the soil so small that they remain suspended in the water.
Ask them to note the differences in sizes of soil particles from the bottom to the top of the sediment. They can examine the sizes of the particles with a magnifying glass through the transparent sides of the bottle.	It should be quite evident that the sediment is made up of two or more layers of small particles of recognizably different sizes.
To summarize their comparison of subsoil and topsoil, based upon particle size, you may want to suggest representing the range of sizes from largest to smallest by drawing sets of circles. To the right of each set of circles they might indicate, in unit measures, the amount of particles of each size.	An example is given here using data collected from two samples.

TEACHING SEQUENCE

COMMENTARY

	Subsoil (unit measures)	Topsoil (unit measures)	Size of Particles
	3/4	1/2	(larger than 1/4 in.)
	1-1/4	1	(larger than 1/10 in. but smaller than 1/4 in.)
	1/2	1-1/2	(larger than 1/18 in. but smaller than 1/10 in.)
	5-1/2	5	(smaller than 1/18 in.)

Summarize Part A by discussing questions such as these:

• Why would it be proper to call soil a mixture?	It is made up of different things.
• What kinds of things are found in soil?	Living things, things that were once alive, and rock materials.
• How big are the particles of material that make up the soil?	There is no one answer to this question since the particles vary in size from those that are so small they remain suspended in water to relatively large pieces of rock.
• In what ways do topsoil and subsoil appear to be different?	The color, odor, and amount of organic material they contain are different.

PART B

1. Introduce this Part of the Activity by showing the class a potted plant.	In this Part of the Activity children will compare the water-holding capacity of samples of topsoil and subsoil.

TEACHING SEQUENCE	COMMENTARY
• What is the plant growing in?	Soil.
• Why is soil important to the plant?	Their responses may include such statements as: The soil holds the plant. The plant gets water from the soil. The plant gets minerals from the soil. All of these are correct; however, emphasize the fact that plants cannot grow without water and the main source of water for plants that grow in soil is the soil itself.
Continue the discussion by asking such questions as these:	
• What happens to a plant when its roots cannot get water from the soil?	First the plant will wilt. If water is not supplied, it will then dry out and die. If some children have not seen this happen, plant several corn seeds in a pot of soil ahead of time. Water well until the plants are about 6-cm tall. This will take about 10 days. Soak the soil and then add no more water. Observe the daily changes that take place. The length of time it will take for the corn plants to wilt and die will depend upon two important factors: the amount of water held by the soil at the time it was soaked and how much of that water it will eventually release to the plant. Both of these factors vary with the type of soil. The humidity of the surrounding air is also a factor.
• When soil is watered, either by rain or by people, what happens to the water that soaks in?	All water that falls on the soil does not necessarily soak into it. Some may run off; some evaporates into the air before it soaks into the soil. Some water continues to percolate deep into the earth. The

TEACHING SEQUENCE	COMMENTARY
	fact that water soaks or percolates through soil can be demonstrated easily by overwatering a potted plant. The water that is not held by the soil will percolate through it and run into the dish or tray under the pot.
• Where must the water that enters the soil be located if it is to be available to plants?	The water must be held by the soil surrounding the roots. The water which passes deeper through the soil does the plant little or no good.
• What property of soil, therefore, is important to keeping water available for plants?	The property has to do with the amount of water soil can hold against the gravitational force that pulls it downward. Water-holding capacity may be defined as the percentage of water held when the soil is completely filled with water. For example, let's assume that a sample of air-dried soil weighed 100 grams and after being saturated with water it weighed 125 grams. The sample of soil absorbed and held 25 grams of water. Since 25 grams is 25% of 100 grams, it could be said that the water-holding capacity of the soil sample was 25%.
Tell the class that they can compare the water-holding capacity of the topsoil and subsoil. One new cup of soil from the topsoil sample and one new cup from the subsoil sample should be spread out on separate sheets of newspaper. If there are large lumps in either sample they should be crumbled. The soil should be left exposed to the air for at least 3 days to dry out.	If you wish to dry out the soil in an oven, pans of it should be left at 200°F for at least 3 hours.
Ask for suggestions regarding how the water-holding capacity	There are several ways in which this might be done. One would

TEACHING SEQUENCE

of soils might be determined.

In addition to the materials and equipment used in Part A, each group should obtain:

1 balance
2 polyfoam cups
1 paper towel
2 4-in. aluminum pans
1 pair of scissors

First they should use a pencil point to punch about 25 holes in the bottom of each polyfoam cup. The holes should be evenly spaced over the bottom of the cup. Then they should cut one round piece of paper towel (one-layer thick) to fit into the bottom of each perforated paper cup. Fit the disc of towel into the bottom of the cup so that all holes are covered. Label one cup "topsoil" and the other "subsoil."

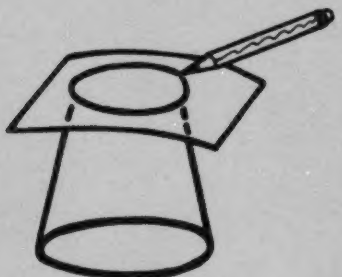
COMMENTARY

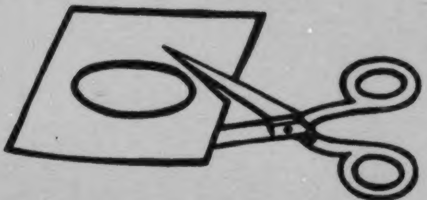
be to place equal volumes of each of two samples in cans with perforated bottoms. A measured amount of water could then be poured into each can and the runoff collected. If the volume of the runoff water is subtracted from the volume of water poured into the can of soil, the difference would be the volume of water held by the soil. Another interesting way of doing it is presented here, based on "before and after" weight determinations.

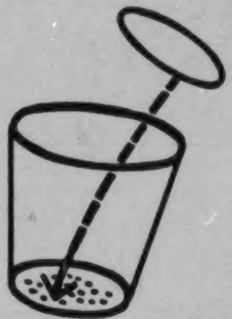
The children can again work in groups of 4. They should divide the things to be done among themselves, taking turns where necessary. If an insufficient number of balances are available for each group to have one, they can take turns with them.

The holes will allow water to enter the paper cup when it is placed in a pan of water.

You might suggest that the children measure for the disc on the bottom of one cup. When the disc of paper towel is placed in the bottom of the cup, it will prevent soil from falling through the holes.







TEACHING SEQUENCE

Next, discuss and demonstrate the following technique: Gently fill each cup about 1/4 full of water as it is held over a pan. Allow most of the water to run out of the bottom of the cup. The remaining water should then be poured out.

The children should weigh the cups while they are still moist on the inside and record the weight of each.

At this point, if you have not already done so, discuss with the children the rationale behind the procedures in this experiment as a whole. It might be helpful for them to set up a kind of Worksheet-organizer for their weight data before they begin:

COMMENTARY

This is done before weighing the cups to include in the total cup weight water that eventually may be absorbed by the paper towel disc and the sides and bottom of the cup.

Have at least two children weigh each cup to check on the results obtained and to refresh their skills. (In COPES, children were introduced to the standard type of equal arm balance and the gram system of weights in Minisequence I of Grade 4.)

	Topsoil	Subsoil
Weight of moist empty cup		
Weight of cup after dry soil is added		
Weight of cup and wet soil		

They should also be given the following specific directions:

Into one moist cup put exactly 100 grams of air-dried topsoil. Into the other, put exactly 100 grams of air-dried subsoil. Again

This can be done by setting the cup on the balance and slowly adding soil until 100 grams is added. If, as in one example, the moist cup and disc of paper

TEACHING SEQUENCE	COMMENTARY
record the weights.	towel weighed 3.1 grams, the cup with dry soil should now weigh 103.1 grams.
Set each cup into an aluminum pan. Then pour 2-1/2 unit-measure cups of water into the bottom of each pan as the bottom of the perforated cup is held down against the bottom of the pan. When you are certain that the cup will not tip over, it is no longer necessary to hold it.	
Observe the top of each soil sample for evidence that water has reached it.	Water will rise in the soil (against the pull of the gravitational force of the earth) by a process known as capillarity. In this case capillarity is brought about by the attractive forces between water molecules and particles of soil. The attraction of the liquid to the solid surfaces is greater than the internal cohesion of the liquid itself. Wetness at the top of the soil sample will become evident by the soil becoming a darker color. The first evidence of this may appear as a small, dark spot within 30 seconds after the cups of soil are placed in water. It may take from 3-5 minutes for the entire soil surface to become wet.
After the entire surface of the soil in each sample has become wet, leave the cup of soil in the pan of water for at least another 10 minutes. Then pour the water out of each pan and allow the wet soil to drain for about 5 minutes before weighing again.	If the water in the pans drops below 1/2 cm, pour an additional small cup (1 oz) of water into each pan.
Finally, the children should	

TEACHING SEQUENCE	COMMENTARY
weigh the samples of wet soil and record the weights. Then, if they subtract the dry-soil-plus-moist-cup weight from the wet-soil-plus-moist-cup weight for each sample, the difference will be the weight of water absorbed and held by each 100-gram sample of topsoil and subsoil.	In one example, the wet topsoil plus cup weighed 141.5 grams. The dry topsoil plus moist cup weighed 105.1 grams. The difference was 36.4 grams. The wet subsoil plus cup weighed 134.1 grams. The dry subsoil plus moist cup weighed 105.2 grams. The difference was 28.9 grams.
After the children have completed this procedure, ask them to compare the water-holding capacity of their samples of topsoil with that of their samples of subsoil.	In the above example, 100 grams of topsoil held 36.4 grams of water whereas 100 grams of subsoil held only 28.9 grams of water. The topsoil had greater water-holding capacity. If one wished to express this as a percentage, it could be said that the water-holding capacity of this sample of topsoil was 36.4% whereas for this sample of subsoil it was only 28.9%. The data can be easily converted to percentages because the sample size was 100.
Since you may get as many quantities for the weight of water by each type of soil as there are groups conducting the investigations, this will provide an excellent opportunity to apply a method of averaging to arrive at weights of water held by the different samples of soil that would be more nearly representative of the larger samples of topsoil and subsoil.	In earlier grades of COPES, children have averaged by "evening off" bar graphs and by "piling-in" squares on a histogram. It may also be done conventionally, by adding the weights and dividing by the number of different ones.
Summarize this Part of the Activity by asking such questions as these:	
• If water-holding capacity were the only factor that determined how well plants	The "if" in this question is very important because there are other factors, such as the

TEACHING SEQUENCE	COMMENTARY
would grow in a soil, which soil would be most suitable for growing plants?	availability of essential minerals, that must be considered. In comparing the soils for which data are reported above, the topsoil, with a water-holding capacity of 36.4 grams of water per 100 grams of soil would be better than the subsoil, which held only 28.9 grams.
• How could you determine which of the two types of soil was really better for growing plants?	Discussion of this question should lead into Part C of this Activity, in which an experiment will be conducted to determine which soil has better growth-producing potentials.
PART C	
1. Introduce Part C by reviewing what was covered in Parts A and B. Then ask the following question:	
• In which soil would you expect plants to grow better, topsoil or subsoil?	Children will probably answer "topsoil."
Encourage them to give reasons for their expectations.	It contains more organic material and holds water better.
Ask them to plan an experiment, using the remainder of their two soil samples, to find out in which soil plants grow better.	It is quite likely that they will suggest that seeds be planted in each of two pots of soil, one of topsoil, the other of subsoil.
In their specific planning, encourage them to consider the following factors that should be controlled:	
a) size of pot	Pots should not be so large that you cannot fill them with the remaining soil.

TEACHING SEQUENCE	COMMENTARY
b) amount of soil in each pot	Soil going into each pot should be approximately the same weight.
c) kind and number of seeds	It is suggested that three corn seeds be planted in each pot to be sure that at least one will germinate.
d) depth of planting	The seeds should be planted about 2-1/2 cm deep.
e) amount of water each is given	Sufficient water should be added daily to keep the soil moist. Each pot should have holes in the bottom through which excess water can drain off. Before soil is put into the pot the holes should be loosely covered to keep the soil from being washed out of the pot.
f) temperature	This is controlled by keeping them in the same place and can be checked with thermometers.
g) light	All pots should be placed on a window sill or where they can get direct outdoor light. The east and south sides of the building are best.
After the experiment has been planned, each working group should be responsible for planting 3 seeds in one pot of each type of soil.	
If the experiment is carried out as suggested above, each group will need the following:	
2 perforated cups from Part B to use as flower pots	The cups should have discs of paper toweling in the bottoms, as before.
2 4-in. aluminum pans, into which the flower pots may be set	
6 kernels of seed corn	

TEACHING SEQUENCE	COMMENTARY
1 sprinkler bulb with spray head	The sprinkler bulbs can be shared among the groups, if necessary.
After all pots have been prepared and planted, they should be arranged in a place where they can get direct light from outdoors. They should then be watered thoroughly. Arrangements should be made for them to be watered daily for the duration of the experiment.	The three seeds should be planted near the center of the pot of soil. Watering should be done gently with a sprinkler bulb. The sprinkler distributes the water over the soil and prevents it from being washed off the seeds. The soil should be sprinkled until water appears in the dish beneath the pot. Most sprinkler bulbs contain about a half cup of water. It is estimated that after the first soaking, half a sprinkler bulb of water per pot each day will be sufficient. With practice, one squeeze on the sprinkler bulb will force out one half of the water it contains. Thus the amount of water given each plant can be conveniently controlled. To keep water supplied to the plants over the weekend when school is closed, it is suggested that the soil in each pot be soaked Friday evening. The pan in which the pot is set should also be filled with water.
Arrangements should also be made to check the temperature of the air around the plants in the morning, at noon, and in the afternoon. Record the temperature on Worksheet I-1.	If possible the three thermometers should be suspended by string directly above the plants for the duration of the experiment. They should be arranged in places that will sample the temperature of the air surrounding all plants. You might want to acquaint the custodian of the building with

WORKSHEET I-1

Name:

DAY	OBSERVATIONS OF PLANTS	
	IN TOPSOIL	IN SUBSOIL

TEACHING SEQUENCE	COMMENTARY
	the experiment and the care with which it is being conducted. You will need the custodian's cooperation to prevent unanticipated accidents to the plants.
2. After the seeds have germinated and the plants have grown to a height of 5 or 6 cm, remove all but one plant in each pot.	The little corn plants should begin to appear in about 4 days. Care should be exercised in thinning the plants to avoid disturbing the roots of the one you wish to leave. The plants to be left in the pots should all be about the same height.
• How will you be able to tell which type of soil produces better growth of the plants? What could you observe or measure?	The children may suggest that they should watch for differences in the height of the plants growing in the topsoil and in the subsoil. They may also suggest using the number and color of leaves as a criterion.
From here on, it is important that, in addition to temperature, such items as the following should be observed and daily records maintained for each plant:	
a) height in centimeters b) number of leaves c) color of leaves	One of the first indications that a plant is not doing well is a change in the color of the leaves from dark green to light green. Eventually the leaf may become yellow, after which it may die.
d) evidence of wilting	This is another indication that all is not well with the plant, especially if wilting occurs when the plant is being properly watered.
In your discussion of the results obtained from periodic	The various observations can be recorded on Worksheet I-1.

TEACHING SEQUENCE	COMMENTARY
observation of the plants, give attention of such questions as these:	
• Are the plants growing straight?	When young, the plants will bend toward the light. They can be straightened by merely turning the pot.
• Which leaves should be measured in determining the height of the plant?	The leaves of the corn plant are long and narrow. The longest leaf in each plant could be measured each time.
• Should more water be given to one of the plants if it shows signs of wilting?	All plants should be given the same amount of water. None should be given extra water.
• Does it affect the experiment for plants to be in drafts?	Not unless the current of air is unusually strong or unusually warm. However, if some of the plants are in even a mild draft whereas the others aren't, the experiment would be affected. Plants in the draft would require more water to sustain themselves.
• Is it possible that on some days all plants may require more water?	If for some reason the place in which the plants are located should become unusually warm, the water allotment for that day should be increased. However, all plants should still receive the same amount of water.
• What should be done if one or more plants are destroyed by insects or rodents?	This may happen. If the destruction results in fewer than two healthy plants remaining for each type of soil, the experiment should be started again and precautions taken to protect the plants. Such unfavorable events are not uncommon in scientific experimentation.
3. Continue observations and record-keeping for at least three weeks. You may want to	Only a few minutes each day are necessary for these observations. The children can go

TEACHING SEQUENCE

distribute another copy of Worksheet I-1 to each group. Then compare the records for plants grown in each type of soil.

COMMENTARY

on to Activity 2, if you wish.

Since you will probably have at least 4 pots of each type of soil, quantitative observations such as height and number of leaves should be averaged for each type of soil. Dates upon which other changes were observed should be compared. For example, here are the corn growth records for two pots each of topsoil and subsoil:

Three corn seeds were planted in each of four pots on September 4. Each pot contained 1000 grams of soil. Pots No. 1 and No. 2 contained subsoil. Pots No. 3 and No. 4 contained topsoil. The seeds were planted at a depth of 2-1/2 cm in each pot. The soil was then watered with sprinkler bulbs until it was soaked through. Each pot was watered daily with the same amount of water. The pots were kept in a warm, well-lighted place. Plants appeared in two pots (one subsoil and one topsoil) within 4 days. Plants were above the soil surface of all pots within 5 days. On the 10th day all plants but one were removed from each pot. The height records on page 40 begin on the 10th day and, after the 11th day, continue for alternate days through the 25th day.

There was no observable difference between the two types of soils in the time that it took for the seeds to germinate and for plants to appear. However, on the 10th day there was a difference in the average height of the corn plants in favor of the topsoil. The average height of plants in the subsoil on the

TEACHING SEQUENCE

- In which soil do plants grow better--topsoil or subsoil?

COMMENTARY

10th day was 7.7 cm, whereas the average height of plants in topsoil was 11.3 cm. The difference in average height persisted through 25 days. On the 25th day, leaves on subsoil plants were showing larger areas of browning and drying than they did on the topsoil plants. At the termination of this experiment on the 25th day, the two subsoil corn plants had only three leaves whereas the topsoil plants had four.

Height of Corn Plants in cm

Day	No. 1	No. 2	No. 3	No. 4
10	8.5	7.0	14.0	8.5
11	11.5	8.5	18.0	12.0
13	19.0	10.0	23.5	18.0
15	24.0	13.0	26.0	23.0
17	25.5	13.5	29.0	27.0
19	27.0	14.0	31.5	31.0
21	26.5	14.5	34.0	33.0
23	28.5	15.0	37.0	36.0
25	32.0	16.0	40.0	39.0

Clearly, topsoil is conducive to better growth than subsoil.

EXTENDED EXPERIENCES:

1. Planning a field trip to one or more of the places listed on page 41, where children can observe the effects of soil erosion, would be highly desirable.

a. Fields where gullies have been cut by unchecked run-off water;

b. Sidewalks next to bare soil where runoff water from rain has washed soil onto the sidewalk;

c. Small muddy streams after a rain caused by runoff water carrying soil into the stream. (Bottles of the muddy water should be taken back to the classroom and allowed to stand until the soil particles have settled out as sediment.);

d. New highway embankments, before grass has grown on the them, where there are gullies formed by runoff rain water;

e. New building projects where topsoil has been scraped away to construct foundations for houses and where runoff water has washed away some of the soil;

f. Unplanted fields where wind has blown away bits of soil and deposited them near wind breaks.

2. A field trip to a wooded area in which there are rocks, to observe the soil-forming process, will serve as an excellent supplement to the discussion in Part A on formation of soil. The place should be an area where lichens and moss are growing on exposed rocks. If the lichens or moss are removed, the rock beneath them will be crumbled more than the rock surrounding the plants. This is brought about by a weak acid that is formed from carbon dioxide given off by lichens and moss. The acid dissolves part of the rock material which causes other parts of it to crumble.

It may be possible to collect a sample of lichens and moss, growing on a small rock, and take them back to the classroom. If this is done, the samples can be kept in an unused aquarium tank. The samples should be sprinkled with water periodically. Between sprinklings the tank should be kept covered with plastic wrap to prevent excessive evaporation of water.

3. In a vacant lot that has not been used for several years have children find three or four different low-growing plants. With a spade, carefully dig around each plant and remove it and its roots from the soil. Shake or wash the soil free. Lay the plants with roots attached on a newspaper and compare the extensiveness of their root systems. If there were a shortage of water, which plant would be best able to survive? If these plants were growing as weeds in a garden, why would it be desirable to remove them?

4. Conduct investigations to determine how the temperature of the soil at different depths varies. Measure the temperature

of the soil at the surface. Do this by "ever-so-gently" sticking the bulb of a thermometer into the soil. Leave it there for at least 2 minutes before you read the temperature. Use a spade or hand towel to dig a hole 6 inches deep. Use the same procedure as described above to measure the temperature of the soil at 6 inches. Now dig down 12 inches and then 18 inches and measure the soil temperature at each depth. How can the differences be accounted for?

5. By using the basic experimental design described in Part C, investigations may be conducted to determine if the growth-producing quality of subsoil can be improved by adding different substances to it:

> Decomposed plant material, such as found near the surface of the soil in wooded areas, is supposed to improve the quality of soil. Does it?
>
> It has been said that ashes from burned wood are good for the soil. Are they?
>
> There are several organic fertilizers processed from the remains of plants and animals or the materials they have produced. Most nurseries or garden stores sell them. Do the garden shops or nurseries in your community sell them? If so, would they add to the growth-producing quality of subsoil? (They should be added to the soil in the amounts recommended by the processor. This will be given on the container in the instructions for use.) There are many so-called commercial fertilizers that are supposed to improve the growth-producing quality of soil. Which of several brands does this best when properly applied to subsoil?

Activity 2 Yeast Plants Interact with a Liquid Environment

In this Activity the children are given two "unknown liquids," to find out what happens when yeast plants are put into them. After they discover that yeast plants interact and produce a froth in one of the liquids but not in the other, they are challenged to speculate about the nature of the two liquids. They find that the liquids are water and a sugar solution. The children then view yeast cells under the microscope and learn that yeast plants are one-celled nongreen plants. Because they cannot manufacture their own food, in order to grow by a process called budding, yeast cells must be in an environment in which there is a food--sugar. With this information children hypothesize regarding the difference in the two "unknown liquids." They then test the hypothesis that one of the liquids was a sugar solution. Finally, they are encouraged to speculate further regarding the nature of the gas that produces the froth in the interaction of yeast with the sugar solution.

MATERIALS AND EQUIPMENT:

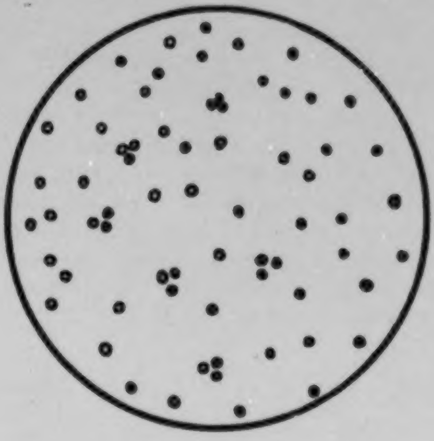
	sugar, granulated, 1 lb (453 g)
20	packages of "active dry" yeast, 1/4 oz (7 g)
10	cups, plastic or waxed paper, 1 oz (30 ml)
8	teaspoons
16	paper towels
16	stirring rods, such as popsicle sticks
8	plastic bags, 11-1/2 in. by 13-in. (29 cm by 32 cm), 1 gal. (3.7 liters) capacity
1	1-pt jar, (0.5 liters)
1	pitcher, approximately 1-pt (0.5 liters)
16	baby-food jars or their equivalent
1	or more compound microscopes with 100x lenses and higher if possible
	microscope slides, cover slips, and medicine droppers.

The number of each will be determined by the number of microscopes available.

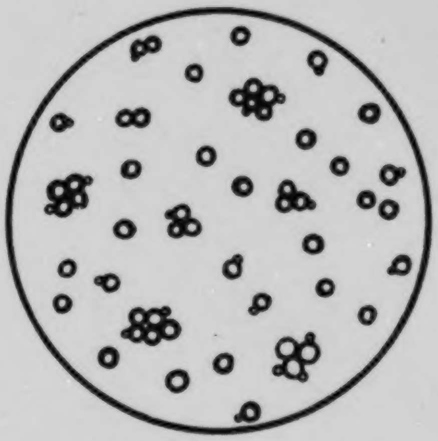
PREPARATION FOR TEACHING:

Prepare a sugar solution by mixing 8 teaspoons of sugar into one pint of water. Put 1/2 teaspoon of yeast plants into each of 8 1-oz cups. Arrange the 16 baby-food jars into 8 pairs. Into one jar in each pair put 1 oz of sugar solution. Into the other jar in each pair put 1 oz of water.

Yeast cells are so small it is impossible to see them with a 40x microscope. With a 100x microscope they appear as shown at the right; with a 450x microscope they appear as shown at the right below. As you will observe, very little detail can be seen with 100x magnification. However with 450x magnification, buds can be seen forming on some cells. It will also be observed that cells may appear singly or in bunches.



It is extremely important that children have the opportunity of actually seeing yeast cells. Therefore, every effort should be made to obtain one or more microscopes with at least 100x magnification. A culture of yeast cells for observation should be prepared by thoroughly mixing just a pinch of packaged yeast cells with 1 oz of sugar solution. The culture will be ready to examine within about 20 minutes. With a medicine dropper, put one or two drops on a microscope slide. Place a cover slip over the drops. If a microscope with both 100x and 450x magnification is being used, observe the cells with 100x first. While the microscope is still set for 100x observation, gently turn the objective that produces 450x magnification into place. Only slight



further adjustment should be required to bring the cells into sharp focus.

If you have never used a microscope to observe yeast cells, it is important that you practice the technique before you begin this activity in class. A section on the Use of the Microscope was presented in the Grade 5 Teacher's Guide.

ALLOCATION OF TIME:

Observations may be made periodically over a period of several hours; however, actual work will take about one and a half hours.

TEACHING SEQUENCE	COMMENTARY
1. Divide the class into working groups. Without telling them what it is, give each group one of the 1-oz cups of yeast cells. Explain to them that this is the material with which they will be working in this Activity. Ask them if they can tell what the material is.	Groups of no more than 4 children are ideal for this Activity. In their efforts to figure out what it is, encourage them not only to look at it, but to feel it and smell it as well. Some may be able to tell what it is by the smell.
If they cannot identify it, show them the package and write "dry yeast" on the chalkboard. Encourage them to tell what they may know about this material.	Yeast was first introduced in Activity 3 of Minisequence IV of Grade 5. If it seems desirable to keep a record of some of the things they say about the dry yeast, make notes on the chalkboard. The children will probably suggest that yeast makes bread rise; hence it is used in baking.
Give each working group a pair of the jars containing sugar solution and water. Tell them that these are two "unknown liquids," and that the problem is to find out what the "unknown liquids"	

TEACHING SEQUENCE	COMMENTARY
are. Have them review some of the methods they have used in other Grades to find out what various materials are.	Remind them that a material is identified by describing its properties. Its properties may include such things as what it looks like, how it smells, how it feels and how heavy it seems. (Caution them about tasting any unknown material.)
Ask the children if they have ever found out what something was by seeing how it interacted with something else.	In Grade 4 of COPES red cabbage extract was used to identify vinegar (an acid) and ammonia (a base). When vinegar interacts with purple cabbage extract, the solution turns red; when ammonia interacts with the extract, it turns green. Later in this sequence red cabbage extract will be used again as an indicator. The iodine test for starch has also been used on several occasions. Iodine solution interacts with starch to produce a blue-black color.
Suggest that they mix dry yeast with each of the unknown liquids to find out if an interaction takes place. Ask them to place each container of liquid on a paper towel. Give each group two stirring rods. Have them mix dry yeast from one of the cups with each of the unknown liquids and stir each mixture thoroughly, using separate stirring rods.	
• What happens to the mixtures? Describe any changes.	Within 5 to 10 minutes, bubbles will begin to form in the sugar solution. Later a brown froth will form and may run down the sides of the sugar solution containers. There will be relatively little action in the container with water.
Be sure the children saw clearly that there was a	

TEACHING SEQUENCE

rather marked interaction between the dry yeast and one of the unknown liquids.

If at all possible give them an opportunity to observe yeast cells under the microscope.

Give the children this additional information:

a. Yeasts are single-celled, nongreen plants.

b. They cannot manufacture their own food as green plants do.

c. They must be in an environment where there is food, water, and a suitable temperature in order to grow and produce more yeast cells.

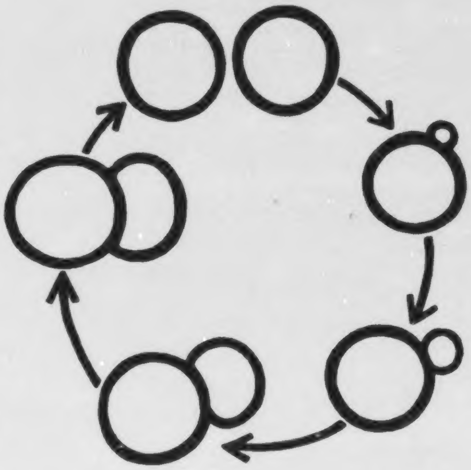
d. They produce more cells by a process called budding. When conditions are suitable, small buds form on yeast cells. The buds increase in size and soon become fullgrown yeast cells. Food and water must be available before this can happen. Sugar is the only food that yeast cells can use.

Now, ask the children to use this information about yeast cells in stating an hypothesis regarding the principal difference between the two "unknown liquids."

COMMENTARY

If it is not possible to use the microscope for this purpose, draw on the chalkboard the yeast cells as shown earlier.

Draw a sequence of sketches, such as these, on the chalkboard to illustrate budding and growth of yeast cells.



TEACHING SEQUENCE	COMMENTARY
• What evidence was there of interaction? In which liquid?	The production of froth in one of the liquids should make it quite obvious that yeast cells were interacting with the liquid.
• What is one possible liquid that the unreacting unknown liquid might be?	The children could suggest any other colorless, odorless liquid that contains no sugar. You might tell them it was water.
• What was probably present in the liquid in which the interaction look place?	Based upon the information about yeast cells, it would be reasonable to hypothesize that for such an interaction to take place the liquid must have contained sugar.
• Can this hypothesis be tested? How?	Eventually the children should suggest making up or obtaining a liquid that is known to contain sugar and seeing if the same kind of interaction is obtained.
Have the groups clean up their baby-food jars. Ask one group of children to prepare a sugar solution, as you had done earlier, and give each group 1 oz of it. Ask another group to put 1/2 teaspoon of dry yeast material into each group's 1-oz cup. Ask a third group to see that all groups have 1 ounce of water in their second jars. After all materials have been distributed, dry yeast material should be mixed with the two liquids and the two setups observed.	
• What is the first evidence or indication that yeast is indeed interacting with the known sugar solution?	Bubbles appear in the solution.
• What do you think causes the	The answer you will probably

TEACHING SEQUENCE	COMMENTARY
bubbles?	get is that gas is being produced.
2. Have the children suggest methods by which you could be more certain that a gas was being produced as yeast interacted with the sugar solution.	Encourage discussion of methods for demonstrating this more convincingly.
Show the class one of the completely deflated plastic bags. Blow a small amount of air into the bag and ask the children to describe what is happening. Blow a little more air into the bag. Again ask them to describe what is happening. Now completely inflate the bag.	The demonstration should be a clue for the children. They should suggest a method whereby the gas given off by yeast cells in the sugar solution may be used to inflate the plastic bag. If they do not make the suggestion, you might offer it.
Give each group a plastic bag. Ask them to prepare a fresh mixture of yeast cells and sugar solution. However, this time they should use 1 cup of sugar solution and an entire package of dry yeast material should be mixed with it. The container of mix should be placed inside a deflated bag and the bag closed with a rubber band.	Make certain that the bag is completely deflated.
Suggest that the children take turns observing the bag over the next 2 hours.	
• When do you first notice a change in the bag?	The volume of gas produced by the yeast cells will not be sufficient to blow up the plastic bag completely in less than about 4 hours. However in about 2 hours, there will be enough of it to distend the bag noticeably.
Conclude this Activity by asking the children if they know what gas is given off by yeast cells to their environment	In asking this question emphasize the fact that the gas is given off by the yeast cells to their environment. In other

TEACHING SEQUENCE

when they interact with a solution of sugar.

Tell them that in later Activities they will find out more about this gas.

COMMENTARY

words the yeast is getting something (sugar) from its environment. It is also returning something, a gas, to the environment.

As suggestions are made regarding the gas write them on the chalkboard. If carbon dioxide is mentioned, do not indicate that it is the correct answer. Save the chalkboard record for the next Activity.

Activity 3 Interactions that Produce Carbon Dioxide

The children begin this Activity by discovering that the gas detected during the growth of yeast cells causes the same kind of change in a cabbage extract as their own exhaled breath. The gas that causes these changes is carbon dioxide. They then go on to investigate a wide variety of living things and again find the same kind of interaction with the cabbage extract. In this way the concept is introduced that organisms give off carbon dioxide. A second objective of this Activity is to demonstrate the concept that when an organism changes, its environment may also change. In this way children are introduced to the two-sided nature of the interaction between living things and the environment.

MATERIALS AND EQUIPMENT:

	sugar, granulated, 1 lb (453 g)
1	red cabbage, medium size
1	hot plate
1	sauce pan, 2-qt (2-liter)
2	3-qt (3-liter) jars with lids
1	jar with lid, 1-qt (1-liter)
	rubbing alcohol, 1 qt
	ammonia, household, 1 oz (30 ml)
	vinegar, 1 oz (30 ml)
5	medicine droppers
20	packages of "active dry" yeast, 1/4 oz (7 g)
15	labels, 1 in. by 2 in. (2-1/2 cm by 5 cm)
2	pitchers
1	bicycle pump with hose
6	teaspoons

supply of paper towels

plastic wrap

1 package of radish seeds and dishes for germination

fresh fruits, such as tomatoes, bananas, apples, grapes, plums, apricots

fresh vegetables (not green), such as carrots, potatoes

flower buds

100 meal worms (obtainable from a pet or aquarium supply store)

For each child you will need:

1 drinking straw

1 polyfoam cup, 6-oz (180-ml)

1 baby-food jar or similar small container

1 wide-mouthed glass jar with lid. Jars may be 1-qt (1 liter), 2-qt (2 liter), or 4-qt (4 liter) capacity. Mouths of the jars should be at least 3-in. (7-1/2 cm) wide. Other wide-mouthed transparent containers of similar capacity may be used.

1 stirrer such as a popsicle stick

PREPARATION FOR TEACHING:

Cut up the red cabbage and boil it for 5 minutes in 4 qt of water. The purple liquid thus produced is cabbage extract. (See Minisequence IV, Activity 1 of Grade 4.) After it has cooled, fill each of the 3-qt jars half full. (This will use up 3 qts of the extract. The remaining 1 qt of cabbage extract can be used as indicated in the next paragraph.) Put one of the 3-qt jars of the purple extract in a refrigerator. It should be labeled "cabbage extract." Refrigeration retards the growth of mold and bacteria. This extract will be used in Sections 1 and 2 of this Activity. Now mix a quart of rubbing alcohol with the 1-1/2 qts of red cabbage extract in the other 3-qt jar. This is now a solution of the extract containing both water and alcohol. The alcohol also retards the growth of mold and bacteria. Thus the alcohol solution of the extract does not need to be stored in a refrigerator. It will remain suitable for use until you are ready for it in Section 3 of this Activity. It is a good idea for the children to be involved in the preparation of the extracts so they will know where the liquids "came from" that they will be working with.

Immediately before using either of the extracts in the Activity, you will need to add ammonia drop by drop with continuous stirring until the color of the extract is bluish-green. It is suggested that you use the leftover 1 qt of purple extract to practice this procedure. Do not add more ammonia than necessary because too much will cause the pigment to break down slowly and turn irreversibly yellow. You have added too much if the extract becomes deep green. If you do this accidentally, add some vinegar drop by drop to restore the bluish-green color.

Before beginning Section 2 of the Activity, be sure the following materials are arranged on tables in the classroom:

1. 30 wide-mouthed glass jars or substitute containers, each filled to a depth of about 1/2 inch with the previously prepared bluish-green cabbage extract. The size of the containers can vary, but you should have 2 containers of the same size to give to each working group. The opening in the containers should be wide enough to make it possible to place a cut-down polyfoam cup in the bottom of the jar, as shown in the diagram on page 57.

2. 30 6-oz polyfoam cups which have been cut down to about 2 inches. Half of the cups should contain about 2 ounces of sugar solution and should be labeled "S." The other half should contain the same amount of water and should be labeled "W."

3. 30 stirrers, such as popsicle sticks,

4. Five babyfood jars, or other small containers, each with 3 packages of dry yeast in it. Arrange the containers in places on the tables where it will be convenient for children to obtain one teaspoon of dry yeast from them. Place a teaspoon beside each container.

Twenty-four hours before beginning Section 3 of the Activity, set out about 50 radish seeds to germinate on moist paper toweling. Lightly cover the germination dish with plastic wrap or a plastic bag to retard evaporation. Other seeds than radish can be used but they will take longer to germinate.

ALLOCATION OF TIME:

The investigations and observation of results will extend over a period of a few weeks. Actual class time will be 2 to 3 hours.

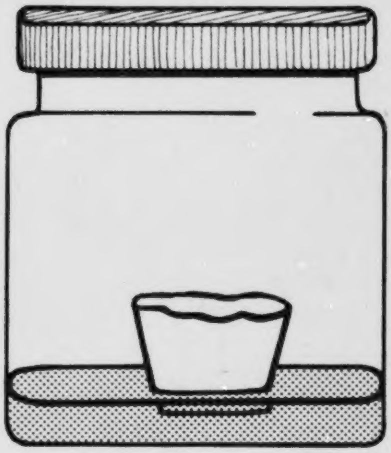
TEACHING SEQUENCE	COMMENTARY
1. Introduce the Activity by asking the children to take a deep breath of fresh air, hold it for a while, and then exhale it.	You should feel free to use any technique here that will call their attention to the breathing process and eventually to the question of how the air we breath out (exhaled air) is different from the air we breath in (inhaled air).
Now ask them to tell in what ways their exhaled air was different from the fresh inhaled air.	They may be relatively well informed on this subject based upon what they have heard or read previously. Exhaled air is generally warmer, moister, and contains more of a gas called carbon dioxide than the surrounding air. They can demonstrate that it is moist by observing condensation when they breathe on a cold surface. They can also demonstrate that it is warmer by breathing on the back of their hands. The exhaled air will feel warmer than the fresher air surrounding their hands.
After it has been suggested that exhaled air contains more carbon dioxide than inhaled air, tell them that there is a way that this can be shown.	So-called fresh air also has carbon dioxide in it. The point here is that exhaled air has proportionally more carbon dioxide in it. Our bodies put additional carbon dioxide into the air.
Distribute, in one of the small containers, a 1-oz sample of the bluish green cabbage extract to each child. Keep some of the original extract for later comparison. Identify the colored liquid as an extract made from boiling red cabbage and then treating it with ammonia.	It is desirable to show them how you did this. Children who have had the experiences in Minisequence IV of Grade 4 will be familiar with this color change.
Distribute a straw to each child, ask them to use it to	Caution: The children should be instructed not to suck the

TEACHING SEQUENCE	COMMENTARY
exhale air gently into their liquids. Ask them to observe any changes in the liquid. Compare it with the sample of extract before exhaled air was blown through it.	liquid into their mouths. By using water, you might demonstrate the correct procedure of first inhaling and then exhaling slowly into the straw.
• How did the extract change as exhaled air was blown through it?	It changed color from bluish-green to blue and then to lavender to purple.
• How long did it take?	About 1 minute.
• What did the color change indicate?	The air or something in it was interacting with the extract.
Tell them that it was the carbon dioxide in the air that caused the color change.	As carbon dioxide dissolves in water, a weak acid called carbonic acid is formed. The change in color was actually caused by increasing the acidity of the extract. This kind of change was also demonstrated in Minisequence IV of the COPES Grade 4 materials.
Now ask the question: Since fresh air has some carbon dioxide in it, how can you be sure that our bodies, through breathing, were actually putting more carbon dioxide into the air?	Let the children discuss ways to do this.
They could set up a control in which fresh (unexhaled) air is bubbled through an equal volume of extract.	To do this, they can use a bicycle pump. Since it may take almost an hour for the carbon dioxide in fresh air to produce a color change, it might be desirable to conduct this test as a class project. Children could take turns working in pairs, one child pumping and one holding the container of extract. Care should be taken not to bubble the gas through the extract so vigorously that it blows extract from the container.
2. What happened in Activity	

TEACHING SEQUENCE	COMMENTARY
2 when the yeast cells grew?	A gas formed.
Remind the children that they had previously made suggestions about what that gas may be. Use questions such as these to direct the discussion:	Show them the list of their suggestions that were written on the chalkboard during the last Activity.
• Is it possible that the gas may have been carbon dioxide? How could you find out?	The discussion should lead to the suggestion that the cabbage extract could be used as an indicator.
Encourage them to suggest several methods by which the gas given off by the yeast cells as they interact with a sugar solution could be tested with the extract.	Some children may suggest that the extract be mixed with the sugar solution. If they try this they will discover that the color does not remain clearly identifiable when the dry yeast material is added. Another suggestion might be to fasten a tube to a container of active yeast cells in a solution of sugar and let the gas bubble through the extract. This is a good idea but difficult to control without special laboratory bottles, stoppers and tubing.
One such method, which they can easily follow, is to put both the extract and a (separate) yeast solution into a closed system and see if the trapped gas that is generated will affect the color of the extract in the same way that breathing into it did.	
Arrange the class into working groups of two. Show the children the assembled equipment. Ask each group to do the following: Put an open container of a well-stirred mixture of dry yeast (1 tsp) and sugar	As indicated in the Preparation for Teaching, each wide-mouthed jar should contain about 1/2 in. of bluish green cabbage extract. The dry yeast should be added to the open, cut-down polyfoam

TEACHING SEQUENCE

solution (2 oz) into one wide-mouthed jar and close it tightly. Put an open container of a well-stirred mixture of dry yeast (1 tsp) and water (2 oz) into the other wide-mouthed jar and close it tightly. Each jar should look like the one in the illustration.



After the experiment has been set up, suggest that the children discuss the changes they expect.

- What evidence of interaction do you predict in each case?

The children should observe the systems periodically for about 30 minutes.

COMMENTARY

cups of water or sugar solution, stirred, and then placed in the jars.

This will be the control setup. You might also want to set up at least one jar containing only the cabbage extract to see if there is any change completely apart from the yeast.

Based upon previous experience the children will probably predict that the sugar solutions and yeast will interact and bubbles of gas will be produced. The water and yeast cells will show no apparent interaction and no gas will be produced. The gas produced by the yeast cells and sugar solution may interact with the cabbage extract in the same way as exhaled air did.

Have the groups make observations at 5-min intervals. Within 30 minutes or less, the yeast cells in the sugar solution will produce enough carbon dioxide to cause a color change

TEACHING SEQUENCE	COMMENTARY
	(bluish green→blue→lavender) in the cabbage extract. As predicted, the water control will not show any apparent change.
Use questions such as these in discussing the results:	
• What were the parts of the closed system within which the sugar solution and yeast cells were placed?	The closed jar, the mixture of yeast cells and sugar solution, the polyfoam cup containing the mixture, the cabbage extract, and the air within the jar.
• What evidence was there that the yeast cells and the sugar solution were interacting?	Froth appeared and filled the cup as before. This was evidence that a gas was being formed.
• As gas was formed and left the cup, where did the gas probably go?	The gas went into the air that was in the system, just as our exhaled gases go into the air surrounding us.
• With what in the system did the cabbage extract have direct contact?	The bottom of the jar, the outside of the cup, and the air.
• Through what part of the system did the gas probably get into the extract?	It might have gone through the cup but since the cup did not leak, it probably went through the air.
• What is the evidence that the gas was carbon dioxide?	It interacted with the cabbage extract and caused it to change color.
• How did the yeast cells change their immediate environment within the sugar solution?	They used the sugar as food, although this could not actually be observed. Here is an abbreviated explanation of what happens: In a sugar-solution environment yeast cells produce chemical substances called enzymes that interact with sugar to produce alcohol, carbon dioxide, and heat energy. This is called alcoholic fermentation. It is the process that

TEACHING SEQUENCE	COMMENTARY
	is used in producing all alcoholic beverages, as well as commercial alcohol. Many sources of sugar may be used, such as fruit juice, grain, and molasses.
• How did the yeast cells change their larger environment within the closed jar?	Carbon dioxide was put into the air in the jar and eventually it went into the cabbage extract. The fact that the extract changed color was evidence that an interaction was occurring.
• What would you expect to happen to the yeast cells when the food in their immediate environment had all been used?	The children may suggest that the yeast cells might eventually die if the food became used up. In that case, they would no longer produce carbon dioxide.
Ask each group to describe the yeast and sugar-solution mixture at the conclusion of their experiment. One member of the group can pour the mixture into a larger container such as one of the baby-food jars. Each jar should be labeled with the name of the mixture, the date, and the names of members of the team. It should then be set aside and observed daily for at least a week.	Their description should include its frothiness, and its yeasty smell. Some children may detect the odor of alcohol. From day to day there will be less and less froth, indicating reduced carbon dioxide production, which may in turn indicate a reduced food supply and a decrease in the total number of yeast cells. After a week the froth will have practically disappeared and the liquid will have become relatively clear, indicating fewer yeast cells. The odor will change to a yeasty alcoholic one and then to a vinegary one.
After a week ask children to report their observations and discuss what the results may indicate about the changes that have taken place in the sugar-solution environment of the yeast.	The yeast cells changed their environment and as a result fewer of them could live in it. The idea that yeast cells could no longer live in it can be tested by adding a half teaspoon of fresh yeast material to the remaining liquid. If this is done, there will be no action because when there

TEACHING SEQUENCE

COMMENTARY

is no more food, the environment becomes a less favorable place for yeast cell production. Their rate of reproduction decreases markedly and the cells go into a resting stage in which they no longer reproduce. If conditions remained unfavorable for a long enough period of time, the cells would die. However, yeast cells are able to maintain themselves in the resting state for many months.

The children have learned that humans and yeast plants, both living things, produce carbon dioxide. The purpose of this Section is to enable them to see that one way in which many, if not all, living things change their environment is by the production of carbon dioxide.

3. Suggest that the children continue to work in pairs. Show them the alcohol solution of the cabbage extract and explain how it was prepared and why it is necessary to use an alcohol-water solution and not just the water solution used earlier.

This Section will extend over a longer period of time than was required for the yeast. Therefore the bacteria or molds which are always present in the air are more likely to grow in the cabbage extract. If these do grow in the extract, they will cause a color change which will interfere with the experiment. The alcohol prevents mold and bacteria from growing, but does not affect the interaction of carbon dioxide with the extract.

Demonstrate how, by adding ammonia drop-by-drop, the color of the extract is again changed to a bluish-green.

TEACHING SEQUENCE	COMMENTARY
Next, encourage each pair of children to select a different type of living thing (organism) from those listed below:	
Germinating seeds	Radish seeds (about 50) which are just beginning to germinate (about 24 hours after sowing on moist paper toweling) will produce enough carbon dioxide to change the color of the extract if kept overnight. Other seeds which are just beginning to germinate should also work well.
Fresh Fruits	Many whole fruits will produce enough carbon dioxide to change the color of the extract within a few hours. These include tomatoes, apples, bananas, peaches, oranges, plums, and apricots. Tomatoes will give the quickest change (about 2 hours).
Fresh Vegetables	Pieces of carrot and potato produce enough carbon dioxide to cause a change in the cabbage extract if left overnight. Green vegetables such as spinach, in addition to producing carbon dioxide, utilize it in photosynthesis and are therefore unsuitable for this experiment.
Flower Buds	Fresh flower buds, such as rose buds, produce enough carbon dioxide to change the color of the extract in 3 to 4 hours.
Mealworms	About 100 mealworms will produce enough carbon dioxide to change the color of the extract in about 3 to 4 hours. The mealworms should be placed in a container with steep glass or plastic sides so that they cannot crawl out. If the mealworms do not produce enough carbon dioxide in about 3 to 4

TEACHING SEQUENCE	COMMENTARY
	hours, they should be removed or the alcohol fumes will kill them.
Have one child from each pair take two equal-sized wide-mouthed jars. The bottoms of the jars should be covered with the bluish-green cabbage extract to a depth of about 1/2 inch.	The jars should be large enough to hold the chosen organism without an unnecessarily large surrounding air space. There will, of course, be a greater volume of extract in a gallon jar containing 1/2 inch of extract than in a quart jar, but this doesn't matter. Only qualitative (color) changes are being investigated here.
	The pitchers should be used for pouring the extract into the jars. It is a good idea to appoint 1 pair of children as the "pourers." Each child can take a pitcher and go to each group to pour extract into the jars.
Then ask each group to find a way to place its selected organism into one of its containers without having it contact the extract. Close the container, and observe it periodically for any changes.	The organisms should not be in contact with the cabbage extract. The children may support them on freshly cut-down polyfoam cups, or other suitable holders such as small aluminum pans, or dishes.
The second container is the control and should be prepared in the same manner but without the organism.	The control container should be the same size as the experimental container.
• What change occurred?	In most cases, the bluish-green extract will have turned blue, although, depending on the length of time the system is left standing, as well as on other variables, the color may change to lavendar or purple and even eventually to red.

TEACHING SEQUENCE	COMMENTARY
• When did a change occur? • Over what period of time did the change occur?	The children should be encouraged to discuss and compare their results. Let them suggest reasons for differences. This should be an open-ended discussion.
Conclude the Activity with a discussion of questions such as the following:	
• In what way have you found the organisms (living things) investigated in this Activity to be alike?	All the organisms investigated--children and mealworms (animals), and plants (seeds, etc.)--produce a similar kind of color change in bluish-green cabbage extract. The substance which caused the change is carbon dioxide. All of these organisms, therefore, although completely different in appearance, share a common interaction property.
• How did these organisms change their environment?	They changed their environment by adding carbon dioxide to it. This was indicated by the color change in the cabbage extract.

EXTENDED EXPERIENCES:

Microorganisms of many different kinds can be grown by putting almost any kind of organic material in jars of water and letting it stand in a warm place for one or more weeks. Dried hay, dried grass cuttings, dried lettuce, and dry lima beans work very well for this purpose. One-pint jars are a good size to use. If tap water is chlorinated, it should be boiled, to force out any chlorine gas, and allowed to cool to room temperature before using it. About an inch of the dry organic material should be put on the bottom of the jar. The jar should then be filled about two-thirds full of water. The uncovered jars should be kept in a reasonably warm place.

After about one week the water will become turbid. Bubbles of gas will begin to appear. These are signs that microorganisms are beginning to develop. Within another week the mixture will have acquired a distinct odor, another sign of life within the jar. If, after two weeks, drops of water from the mixture are examined with a microscope, using 100x and 450x magnification, a variety of microscopic animal organisms can be observed swimming around.

One question that children are sure to raise is: "Where did they come from?" The organisms were probably on the organic material in a resting stage, or floating around in the air. The mixture of organic material and water, along with a reasonably warm temperature, provided the organisms with an environment ment within which they could grow and reproduce.

After several weeks the odor produced by the microorganisms as they decompose the organic material may become quite unpleasant. However, if the mixtures are kept until all the water evaporates and the material dries up, it will have been possible to observe, within a relatively short time, a series of environmental changes accompanied by changes in populations of living things. The series would have gone from a dry, lifeless-appearing material through obviously active periods of lively interaction, back to a dry lifeless-appearing material.

Activity 4 Plants and Water Vapor

In Activities 2 and 3, the children demonstrated that plants and other living things produce carbon dioxide which is then released into the environment. This is one way in which a community of living things, that includes green plants, interacts with its environment.

The children explore a second interaction of plants with their environment in this Activity. The leaves of a green plant are shown to release water vapor into the surrounding air. From this observation, the children are introduced to the concept of relative humidity: they then learn how to measure it by using wet- and dry-bulb thermometer techniques. They measure the relative humidity in a number of different environments and find that there are significant variations. Then they hypothesize regarding the effects of such variation upon the evaporation of water from open pans. Experiments are conducted, and the children discover that, in the same period of time, more water will evaporate in a place where the relative humidity is low than in a place where the relative humidity is higher. From this evidence, an inference is made concerning relative humidity and its effect upon water loss from plants.

Through an examination of their experiences with the drying of wet surfaces, such as their hands, the children hypothesize regarding two other factors that affect evaporation of water from surfaces exposed to the air. One has to do with relative areas of exposed wet surfaces and the other with currents of air moving over wet surfaces. Experiments with open pans of water confirm their hypothesis. From these results they infer that the same factors will have an effect upon water loss from leaves of plants. Further experimentation confirms these inferences.

MATERIALS AND EQUIPMENT:

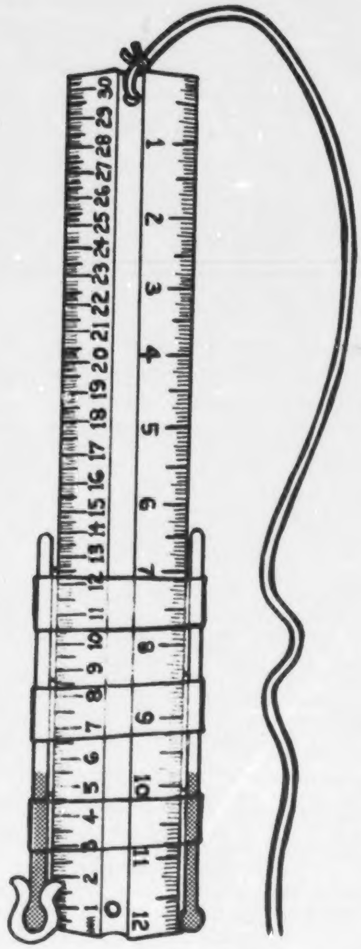
For the class you will need:

15	plastic bags, 11-1/2 in. by 13-in. (29-cm by 32-cm) 1-gal (3.7 liters) capacity
8	geranium plants, potted, approximately 12 in. (30 cm) tall, with at least two well-leafed branches
1	ball of string

1	pair of scissors
1	jar of white petroleum jelly (vaseline), 4 oz
1	roll of plastic tape
7	rulers with hole near one end, 12-in. (30-cm)
14	thermometers, -20°C to 50°C
7	pieces of cotton cloth, 1-in. by 2-in. (2-1/2 cm by 5-cm)
7	cups, 1-oz (approx. 30 ml), waxed paper or plastic
12	shallow cookie sheets or cafeteria trays, all of the same size
1	or more measuring cups, 1 cup
1-8	balances, the same as those called for in Activity 1
12	baby food jars
1	electric fan
18	test tubes, 5/8-in. by 4-in. (13-mm by 100-mm)
6	aluminum pans, 4-in. (10-cm) across the top, or their equivalent
6	aluminum pans, 8-in. (20-cm) across the top, or their equivalent
7	copies of the relative humidity conversion table shown on p. 75
30	copies of Worksheet I-2

PREPARATION FOR TEACHING:

On the day before you begin this Activity fill a dry plastic bag with air and place it over the leaves on one branch of one of the geranium plants in full view of the children. Gently grasp the edges of the open end of the bag around the stem of the branch at a position just above where it grows out from the main stem. Tie the bag with a string so that little or no air can escape from it. Soak the soil around the plant and place it on a window ledge in the sunlight. Within several hours drops of water will have condensed on the inside of the bag.



As explained on pages 73-76, relative humidity can be determined by using a sling psychrometer, which consists of two thermometers mounted on a frame that can be whirled rapidly in the air. The bulb of one thermometer, wrapped with two thickness of cotton cloth, is dipped into water before it is used and is, therefore, the wet bulb. The other is the dry bulb. You will need to construct a sling psychrometer for demonstration in Part B. Use a 12-inch ruler as a frame; the ruler should have a hole near one end into which you tie one end of a two-foot string. Two Celsius thermometers should be selected that register the same temperature. One should be attached to each side of the ruler near the end opposite the string, as shown in the diagram. Two thicknesses of a piece of cotton cloth, 1 inch wide, should be wrapped around the bulb of one thermometer. Both thermometers should be securely attached with plastic tape, with the bulb-ends at the lower end of the ruler.

The 8 geranium plants will be used a number of times in different experiments throughout this Activity; therefore arrangements should be made to keep them in good shape. They should be watered every day and kept in direct sunlight. If you do not have direct sunlight in your room, arrange to keep the plants where there is direct sunlight when you are not using them.

ALLOCATION OF TIME:

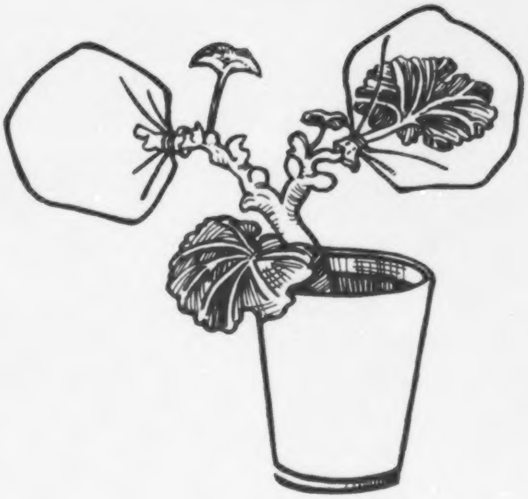
Although a number of the observations to be made in this Activity will extend over a period of several days, the actual class working time should be approximately 6 hours.

PART A

TEACHING SEQUENCE	COMMENTARY
1. Introduce Part A of the Activity by showing the children the geranium plant with the plastic bag tied over the leaves on one of its branches. After they have had a chance to observe it closely, ask them to describe what they have seen.	In addition to the general observation of a bag tied over one branch of the geranium, they should note that the bag is somewhat inflated with air and that there are drops of water on the inner sides of the bag.
• How did the water get onto the inner sides of the bag? As they begin thinking about this problem encourage them to recall other instances where they have seen something like this happen.	Under certain conditions water vapor in the air may condense (change from a gas to a liquid) and be deposited on surfaces with which it comes into contact. (This has been demonstrated previously in COPES Activities for earlier grades.) On warm humid days they undoubtedly have seen that water vapor from the air condenses on containers of cold drinks. On cold days they have seen that water vapor from the air inside a warm building condenses on the cold windows.
• Did the water come from the air in the bag or from the plant?	Among the hypotheses they may suggest, two appear quite reasonable: a) The water came from the leaves and then condensed on the sides of the bag; b) The water came from water vapor that was already in the air with which the bag was inflated. The leaves had nothing to do with it.
Encourage the children to suggest experiments that could be performed to test their	A very simple class experiment could be done by inflating a plastic bag with room air,

TEACHING SEQUENCE

hypotheses.



If you have enough geranium plants, divide the class into

COMMENTARY

tying it off, and setting it aside for the rest of the day to see if water condenses on the inside of it. (Caution: Keep the bag at room temperature. If the air in the room is warm and humid when it is put into the bag, and, if the bag is then put into a cool place some water vapor will condense.)

Another experiment would be to remove all the leaves from one branch of a geranium plant and tie a bag over the naked branch. What happens in this bag should be compared with what happens in a bag tied over a leafed branch on the same plant. The plant should be placed in direct sunlight, if possible. The illustration to the left shows a geranium plant set up for such an experiment.

Still another experiment would be to cover both sides of all leaves on one branch with white petroleum jelly (vaseline) to prevent water evaporating from the leaf. A bag could then be tied over the branch and the results compared with those of a bag tied over a branch on which the leaves were not covered with vaseline. Here, too, plants should be placed in direct sunlight if possible. (Condensation should appear in the bag over the uncovered leaves first.)

TEACHING SEQUENCE	COMMENTARY
groups of 5. Each group should be assigned the task of performing one of the experiments.	It would be highly desirable to have at least two groups performing each of the experiments so that results can be compared. All experiments should be set up first thing in the morning so that observations can be made throughout the day. Where possible, controls should be run.
Have one member of each group record on the chalkboard the time of his or her group's first observation of moisture formation on the sides of the bag, if any is formed.	In all of the above experiments differences in transpiration rate will be judged subjectively by noting the time that condensation appears on the sides of the bag and/or the relative amounts of water that condense on the bag.
At the end of the day, have each group report its findings.	
• What conclusion would seem reasonable regarding the source of water in the plastic bag?	
Let the children discuss this question and their findings at length:	The findings should lead to the conclusion that the leaves of geranium plants give off water. The loss of water, as a gas or vapor, from plants is called *transpiration*.
• In what form did the leaves give off water?	In the form of a gas or vapor.
• Why do you think the water was in the form of water vapor?	They could not see it leave the plant. However, it probably left the plant since it later condensed on the bag.
• How did the water get from the leaves to the sides of the bag?	In order to get from the leaves to the sides of the bag, it must have traveled through the air.

TEACHING SEQUENCE	COMMENTARY
• Where was the water vapor before it condensed on the bag?	It must have been in the air inside the bag since air is the only material that had contact with both the leaves and the bag.
• Do you think plants such as geraniums are always giving off water vapor into the air?	Yes, in fact over 95% of the water taken up by most plants from the soil is lost through transpiration. In one day a single corn plant may lose to the air surrounding it as much as a gallon of water. A single 10-foot apple tree may lose as many as 5 gallons of water. A date palm in a desert oasis may lose daily as many as 125 gallons of water to the dry air surrounding it. Thus, plants change the air surrounding them by adding water vapor to it.
PART B	
1. Review the discussion of the relative amounts of water lost by plants, as presented at the conclusion of Part A.	In Part B, the relationship of water vapor to relative humidity is discussed. In addition, the idea, first developed in Grade 3 of COPES, that as water evaporates from an object the temperature of the object is reduced is also reviewed.
• If one mature corn plant loses one gallon of water to the air in one day, how much do you think an acre of corn would lose in one day?	An acre is 4840 square yards (43,560 square feet). If there is one mature corn plant per square yard, there would be 4840 corn plants per acre. Thus an acre of corn would lose 4840 gallons of water a day. That is more than one half the amount of water it would take to fill a large gasoline tank truck. The largest of the tank trucks hold 8500 gallons of gasoline.
• What effect does the loss of this amount of water have	It increases the amount of water vapor in the air.

TEACHING SEQUENCE	COMMENTARY
upon the air?	
• When the air has a good deal of water vapor in it, how do we describe it?	We say that "the humidity is high." However, there is a more accurate way of explaining the phenomenon. The actual amount of water vapor in a sample of air at any one time is called the *absolute humidity*. It is expressed in grams of water per cubic meter of air. *Relative humidity* is more commonly used; it is the amount of water vapor the air actually contains, compared with the total amount it could hold at any one temperature. Relative humidity is expressed in percentages. When the air is holding all the water vapor it can at a given temperature, it is saturated. Its relative humidity is 100%. This was the condition of the air in the plastic bag in Part A when water vapor was condensing on the inside of the bag.
• How can you determine the relative humidity of the air?	The children may have had some experience with wet- and dry-bulb thermometers. However, even if someone suggests such thermometers, proceed with the development of the idea underlying their use.
The following questions can help to develop the rationale for using wet- and dry-bulb thermometers in determining relative humdity.	
• What happens to an object when water evaporates from it?	Eventually it may become dry, but it also becomes cooler as the water evaporates. It becomes cooler because heat energy is taken from the object to change water from a liquid to a gas. The cooling effect of evaporation can be demonstrated by putting water on

TEACHING SEQUENCE	COMMENTARY
	the back of your hand and blowing on it. As the water evaporates, the hand feels cooler. (These ideas were introduced in Minisequence V, Activity 5 in Grade 4.)
• On a warm day, when the relative humidity is high and you are perspiring, why is it hard for you to become cool?	Perspiration, which is mostly water, evaporates slowly when the relative humidity is high. Therefore the body is not cooled as much as on a day when the relative humidity is lower. The more water vapor in the air, the slower water evaporates from objects such as people and leaves.
Show the class two thermometers. Have one of the children read the temperature as it is registered on each one of them.	Make certain that the thermometers have been checked before class and that they register the same temperatures.
• What would happen to the temperature, as registered on one of the thermometers, if you put a wet cloth over its bulb?	Based upon earlier discussion they should predict that the thermometers with the wet bulb would register a lower temperature.
Put the wet cloth over the bulb and have them note that, in fact, the temperature drops. Tell them that you are going to call this thermometer the wet-bulb thermometer.	
• Why does the wet-bulb thermometer register a lower temperature than the dry-bulb thermometer?	It should be clear that this happens because water is evaporating from the cloth, thus cooling it and the wet bulb.
Have someone fan the wet cloth over the wet-bulb thermometer and see if they can make the temperature go down farther. When it has gone down as far as it apparently is going to go, have the registered temperature of both thermometers	

TEACHING SEQUENCE	COMMENTARY
read, and record them on the chalkboard.	
Ask what the difference was between the temperatures registered by the wet- and dry-bulb thermometers.	The dry bulb thermometer, of course, registers the temperature of the air. Depending upon the relative humidity, the difference may be as much as 3 or 4 degrees.
• When would you expect the difference to be greatest and when would you expect it to be least?	When the relative humidity is lowest, the difference would be greatest. The less water vapor there is in the air, the more rapidly the water evaporates and the lower the temperature recorded by the wet-bulb thermometer. When the relative humidity is highest, there would be the least difference.
Show them the sling psychrometer you have made and explain how it was constructed. Then show them how it is used.	Wet the cloth surrounding the bulb on one side of the ruler. Whirl the psychrometer in the air at least two minutes, then record the temperature registered by each thermometer.
• How could we find out what the relative humidity is in this room using this instrument? Distribute copies of the relative humidity conversion table to the children.	The difference between the temperatures recorded by the wet and dry bulb thermometers would need to be determined first. After the difference is determined, the relative humidity can be read from tables such as the one on page 75. Copies can be made using the duplicated table on page 467.
• What is the difference in temperatures between the two thermometers?	Here are actual readings after a pyschrometer was whirled in the air for two minutes: dry-bulb thermometer 26.5°C, wet-bulb thermometer 21.0°C. The difference was 5.5°C.
Use the table to find the relative humidity. You will want to work through this	Since 26.5°C is nearer 27°C than any other temperature in the first column in the table,

CONVERSION OF THERMOMETER READINGS INTO RELATIVE HUMIDITY (%)

TEMPERATURE OF DRY-BULB IN °C.	DIFFERENCE BETWEEN WET-BULB AND DRY-BULB IN °C.								
	1	2	3	4	5	6	7	8	9
+9	88	76	65	53	42	32	22	12	
+12	89	78	68	58	48	28	30	21	12
+15	90	80	71	62	53	44	36	28	20
+18	90	82	73	65	57	49	42	35	27
+21	91	83	75	67	60	53	46	39	32
+24	92	85	77	70	63	56	49	43	37
+27	93	86	79	72	65	59	53	47	41
+30	93	86	79	73	67	61	55	50	44

TEACHING SEQUENCE	COMMENTARY
example with the children.	it is used. To find the relative humidity, go across the table at 27°C to the column for a difference of 5.5, which is between 5 and 6. As you will note, the relative humidity is between 59% and 65%. The halfway point between these two percentages is 62%. Thus the relative humidity at the time these measurements were made was 62%.
2. Divide the class into groups of 4 or 5 children and give each group the materials for making a sling psychrometer.	The following materials will be needed. 1 ruler, 12-inch (30-cm) with hole near one end 2 thermometers (pre-tested to ensure their coincidence) 1 piece of heavy cord 2 ft (60 cm) long 1 piece of cotton cloth; 1 inch x 2 inches (2 1/2 cm x 5 cm) 1 cup, plastic or paper, 1 oz (30 ml), containing water 1 copy of the conversion table a roll of plastic tape
After they have constructed their sling psychrometers, have them determine the relative humidity in a number of different places of their own choosing. Pass out Worksheet I-2. Ask that they use it to record their findings.	Encourage them to select places in which they would expect to find differences in the relative humidity. These might include: their class room, outdoors in the sun and in the shade, over a grassy plot and over a parking area or play area. This data collection should be a "take-home" assignment. It can be done at lunchtime, after or before school, etc.
When all groups have completed collection of their data on relative humidity in at least	

WORKSHEET I-2 Name:

Data on Relative Humidity

TIME AND PLACE	DRY-BULB TEMP.	WET-BULB TEMP.	TEMP. DIFF.	REL. HUM.

TEACHING SEQUENCE

3 places, have them report to the class.

Discuss what may have accounted for the differences in relative humidity they found for the same area.

Based upon their data regarding relative humidity in different areas, ask them to

COMMENTARY

Here are data that were collected at various places.

PLACE	DB TEMP	WB TEMP	TEMP DIFF	REL HUM
Parking Lot	23.0	22.0	1.0	91%
Park Lawn	23.5	22.5	1.0	91%
Kitchen	25.0	22.5	3.0	80%
Bedroom	25.5	22.5	3.0	78%
Basement	25.0	21.0	4.0	71%

A number of variables in the performance of the technique may account for differences. Some are:

1. Improper reading of the thermometers.
2. Failure to swing the sling psychrometer until the wet-bulb reached its lowest level.
3. Thermometers not being properly adjusted in the beginning to register identical temperatures under the same conditions.
4. Where dry-bulb temperatures and/or difference between wet-bulb and dry-bulb did not correspond exactly with those in the table, the difference may not have been interpreted in the same way.

In the data reported above, the relative humidity in the air above the lawn was 91% whereas

TEACHING SEQUENCE	COMMENTARY
identify two places where the relative humidity appears to be quite different.	in the basement it was only 71%.
• In which place would you expect water to evaporate faster?	Using the above data you would expect it to evaporate faster in the basement.
Encourage them to plan experiments for testing their hypotheses.	A simple experiment would be to use two rather shallow but wide pans or dishes of the same size (area). Put the same amount of water into each. (Amounts could be measured as weights or volumes.) The shallow pans should then be placed in each area for the same period of time and then the amounts of remaining water compared. In such an experiment the relative humidity should be checked every hour or so to be sure the difference persists.
Conclude this part of the Activity by asking the children to discuss how plants affect relative humidity and how relative humidity affects plants.	As plants transpire, they add water vapor to the air. This increases the relative humidity. As the relative humidity increases, plants lose less water. In this way, plants interact with their environment.
PART C	
	In this Part of the Activity children investigate the relationship of two factors to the amounts of water evaporated from different surfaces.
1. Review what children found out about relative humidity and its apparent effect upon evaporation of water. Ask if there may be other conditions or factors that would cause water to evaporate faster.	They should have found that water evaporates faster when the relative humidity is low.
To relate this to experiences	

TEACHING SEQUENCE	COMMENTARY
they may have had, ask such questions as these:	
• Why will swinging your wet hands in the air dry them faster than merely holding them in the air?	Swinging the hands in the air increases the rate of evaporation. If the hands were not moved, the relative humidity of the air immediately surrounding them would become higher and the rate of evaporation from the hands would decrease. However, by moving them, they are kept in contact with air in which the relative humidity is not as high. Therefore, the water will evaporate freely.
• Why are wet clothes spread out when they are hung to dry?	Spreading them out exposes more of the wet surface to the air, thus increasing the rate at which the water will evaporate from the clothes.
Ask how experiments could be conducted to determine how much of a difference it makes, in the amount of water evaporated, to move air over the surface or to increase the surface area of water exposed to the air.	In planning their experiments, encourage the children to include a technique for actually measuring the amount of water evaporated under each of the various conditions. It is suggested that a balance be used to weigh the water before and after exposure to each of the experimental conditions.
First you might guide the class in planning an experiment to determine how much more water would evaporate from a container when air is moved over it continuously than would evaporate from one in which the air above it is relatively undisturbed:	You may prefer to allow the children to form small groups and do their planning without your guidance. However, the questions listed under Teaching Sequence are those with which they will eventually have to deal in order to plan controlled experiments.
• How many containers of water should be used?	At least two, one with moving air above it and one with undisturbed air above it.
• What types of containers should be used?	Containers such as pans with relatively large open areas exposed to the air. The

TEACHING SEQUENCE	COMMENTARY
	containers should be the same size.
• How much water should be put into each container?	The same amount.
• How should the amount be measured?	Weighing the pan and water before and after exposure on a balance is better than measuring volumes. In measuring volumes, there might be accidental loses because it would be necessary to pour the water out of the pans. Furthermore, all of the water may not be removed each time, increasing the amount of error.
• By what means should the air be made to move over the one container of water?	It would be desirable to use an electric fan. However, if an uninterrupted breeze is blowing through an open widdow, one container could be placed in the breeze for the period of time necessary to get measurable results.
	Here are the results of a sample experiment: Two 4-inch aluminum pans were used. Water was poured into each pan until the pan and water weighed 109.4 g. The surface of the water in each pan was within 1/2 inch (1 cm) of the top of the pan. One pan was placed on one table and the other pan was placed in front of an electric fan on a table in another part of the room. After 4 hours the pans were again weighed. Both pans of water weighed less. However, the pan of water over which air had been moving weighed 14 g less; the other pan weighed 1.6 g less.
After the experiment has been planned to the satisfaction of all, have the children	

TEACHING SEQUENCE	COMMENTARY
proceed in a similar manner to plan another experiment to determine how much water evaporates from pans with different surface areas exposed. • What data need to be collected for this experiment?	Here is the manner in which an experiment using rectangular cake pans was conducted: The surface dimensions of one were 12 in. by 8 in. (area 96 sq in.). The other pan was 8 in. by 8 in. (area 64 sq in.). Three cups of water were put into each pan. The larger pan of water weighed 879 g and the smaller one weighed 742.2 g. The pans were then placed side by side on a table and left undisturbed for 24 hours. They were again weighed. (The pan of water with the larger surface area exposed to the air had lost 141.6 g of water, whereas the pan with the smaller surface area exposed to air had lost only 108 g of water.)
After both experiments have been planned, again divide the class into groups of 4 and 5. Half of the groups can do the first experiment and the other half the second one. When results have been obtained, have the groups compare their findings.	Let the children construct their own data sheets for these experiments.
	Whereas quantitative findings may not be exactly the same for each group, the trends should be the same: Moving air causes more water to evaporate than still air. More water evaporates when larger surface areas are exposed to the air.
2. Now ask how these findings can help explain the loss of water from plants. Ask for ideas regarding the manner in which experiments may be conducted to answer these questions:	
• Would a greater leaf surface	As a result of their findings,

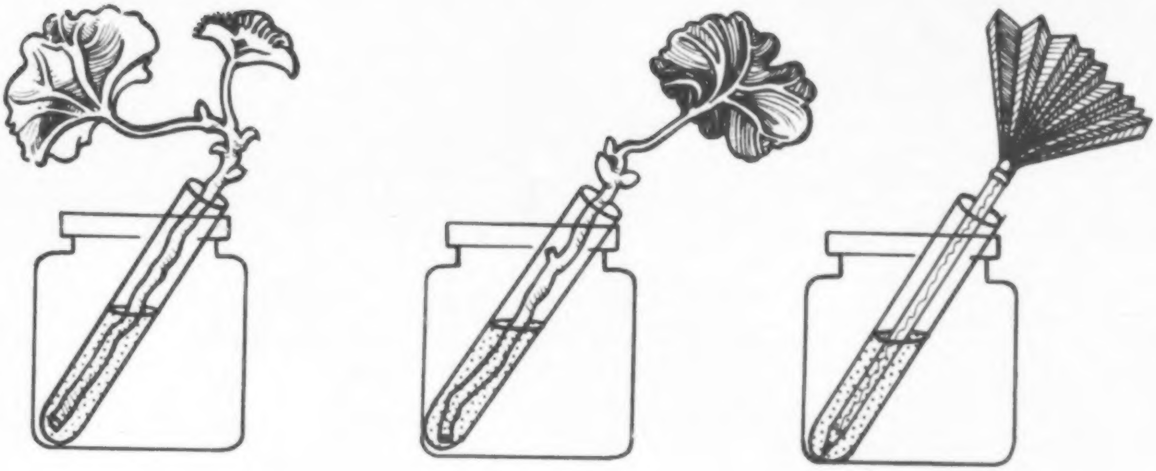
TEACHING SEQUENCE	COMMENTARY
exposed to the air result in greater water loss from plants? • Would moving air (wind) result in greater loss of water from plants?	the children may expect that the larger the surface area of leaves exposed to the air, the greater the water loss and that winds would increase water loss from plants.
Help the children see that by asking specific questions such as those, what needs to be done in designing an experiment becomes clearer.	The word greater in the first question implies that some estimates or quantitative measurements will have to be made; first with reference to the area of leaf surfaces and second, with reference to the amount of water lost. In the second question only the amount of water lost will need to be measured. We detect the fact that air is moving by observing the movement of things with which it comes in contact. However, if the speed of air were a factor, a measurement of it would have to be made.
Suggest that the children plan their own experiments. Ask questions such as these to guide their thinking:	
• What kinds of plants should be used?	Since the geranium plants are still on hand, they should be used.
• What part of the plant should be used?	A branch with relatively few, or smaller, leaves could be used to compare its water loss with a branch containing more or larger leaves. The second branch should have obviously greater leaf surface exposed. To measure the actual areas of leaf surface is too difficult for children to do.
• How should the branches and their leaves be treated?	The branches could be cut off and their stems put into test tubes containing water. Test tubes can be approximately 5/8 in. x 4 in. (13 mm x

TEACHING SEQUENCE	COMMENTARY
	100 mm). (This size test tube is called for in later sequences.) Cuttings prepared in this manner can later be kept in larger containers of water until they grow roots and then potted so as to produce new geranium plants.
• How can you determine how much water is lost by the leaves?	Begin with the stem and test tube filled with water. Weigh it in the beginning and each day for a period of four days. Test tubes can be put into the babyfood jars and left there for weighing. It will not be necessary to deduct the weight of jar and test tube each time because their weight will be the same each time. The loss in weight will be accounted for by loss of water.
• What controls should be set up?	One full test tube of water should be set up without a geranium cutting in it. Rather than a geranium cutting, it should have a pencil (for instance) in it with a small paper fan attached to the upper end of the pencil. The pencil occupies approximately the same space within and above the test tubes as the cuttings do. Whatever water is lost from this setup will approximate the amount evaporated from the surface of the water in the test tubes with the cuttings. The amount it loses should then be subtracted from the amount lost from test tubes containing cuttings to find the amount actually lost by the leaves.
Ask the children to set up their experiments and run them in groups of 5 for four days. Have each group then report on its findings.	Here are the findings from one experiment conducted as suggested above. The weights recorded are for the jar in which the test tube was held,

TEACHING SEQUENCE

COMMENTARY

plus the test tube, water, and cutting. No. 1 was the setup for the cutting with the estimated larger leaf surface exposed. No. 2 was the setup for the cutting with the estimated smaller leaf surface exposed. No. 3 was the control setup of test tube, pencil, attached fan, and water.



Set-ups	Days			
	1	2	3	4
No.1	118.8g	116.1g	113.6g	111.8g
No.2	111.0g	109.2g	108.4g	107.8g
No.3	111.5g	110.8g	110.3g	109.9g

Setup No. 1 lost 7 grams of water in the four days, No. 2 lost 3.2 grams, and No. 3 lost 1.6 grams. From this it can be inferred that the leaves in setup No. 1 lost 5.4 grams (7-1.6), and in No. 2 they lost 1.6 grams (3.2-1.6).

TEACHING SEQUENCE	COMMENTARY
Ask what conclusions can be made based upon their findings.	The findings will clearly lead to the conclusion that the greater the leaf surface exposed to the air, the greater the loss of water.
Now ask the children how they can use the setups they presently have to conduct an experiment that will help them to answer the question regarding the effects of moving air on water loss from leaves.	One workable plan is to refill their three test tubes as before, weigh them, and set them in an air current produced by the electric fan. They should also be located in a well-lighted place. The setups should be weighed at the same intervals they had previously been weighed.
After they have completed their weighings for the fourth day, have them make comparisons, setup by setup.	Here are the findings obtained when the setups previously referred to were put into an air current produced by a fan:

	Days			
Set-ups	1	2	3	4
No.1	119.1	112.0	105.1	101.2
No.2	110.8	105.7	100.2	96.3
No.3	112.1	109.3	106.8	105.1

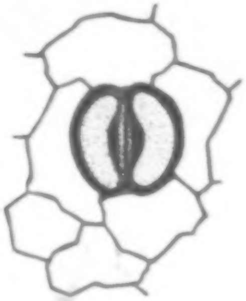
	Note that a considerably larger quantity of water was lost by geranium leaves when they were placed in a current of air.
3. Summarize this Activity by discussing such questions as these:	
• How does water loss from the leaves of green plants affect the air surrounding them?	As water vapor mixes with other gases in the air, it increases the relative humidity of the air.
• How does the loss of water from leaves affect their temperature?	Heat energy is used in changing water from a liquid to a gas. As heat energy is taken from the leaves, their

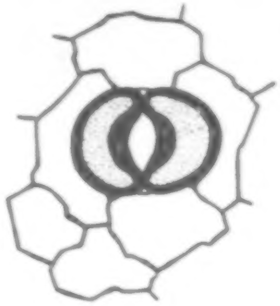
TEACHING SEQUENCE	COMMENTARY
	temperature becomes lower. If this did not happen, leaves in direct sunlight would become seriously damaged.
• What are some of the environmental factors affecting water loss by leaves?	Radiant energy from the sun, relative humidity of the air and movement of the air.
• What is a plant factor that would affect water loss by leaves?	The relative size, shape, and number of leaves, all of which affect the surface area exposed.

EXTENDED EXPERIENCES:

1. A modification of the experiment described on page 000 might be performed to find out from which side of the leaf most of the water evaporates. The children could set up some plant leaves with vaseline on the upper side and some with vaseline on the lower side. Most of the water evaporates from the underside of the geranium leaf where there are more tiny openings called *stomata* in the epidermal layer of cells. The air moving out of the stomata contains more water vapor than the air moving in. The plant loses much of its water in this manner. Similar experiments could be conducted with other types of potted plants such as *Begonia, Coleus,* and English Ivy. None of these plants has stomata in the upper epidermis of their leaves.

2. Stomata in epidermal cells of leaves can be observed with the microscope at 450x magnification. To view them, wet mounts can be made of extremely thin layers of the lower epidermis as it is peeled off the leaf. Here is what a stoma looks like closed and open.





3. The relative rates and/or amounts of transpiration from different types of trees, shrubs, and garden plants can be investigated, as they are growing, by using the plastic bag technique. The bags can be tied onto the ends of branches without harming the plant. Where such comparisons are being made, care should be exercised in getting approximately the same number and size of leaves into each bag. Finally an experiment might be done to find out if a branch of leaves in the sunlight will transpire more than a shaded branch. (Radiant energy heats the leaf and increases the rate of transpiration.)

Plants such as evergreen trees and cacti have modified leaves that lose relatively small amounts of water by transpiration. The needles of the evergreen are its leaves; the spines on a cactus are its leaves. In both types of leaves the surface exposure is much less than it is in broad-leaf plants. An investigation of water loss from these kinds of plants would be a highly interesting project.

4. Some children may be interested in conducting a long-term (3 to 6 month) survey of variations in relative humidity in several different nearby environments such as: a playground, a grassy park, a woods, a swampy area, and a large parking lot. If possible, the relative humidity should be checked every day at about the same time. After the survey is completed, a report could be written in which the findings of the survey are reported, along with possible explanations of differences in relative humidity from day to day and from one place to the other.

Activity 5 Action in the Underground

This Minisequence was introduced with an investigation of soil. The investigation included consideration of the interaction processes by which soil is formed, the complexity and variability of its composition, one of the ways it interacts with water, and the comparative plant-growth-producing qualities of different types of soil. It was later shown that one way in which plants and animals change their environment is to release carbon dioxide into it. However, green plants, during their food making periods, remove some of the carbon dioxide and replace it with oxygen. This carbon dioxide-oxygen cycle is one of the ways in which a community of living things interacts with its environment. In the preceeding Activity the children found that plants also change their environment by adding water vapor to it. Such changes, in turn, have an effect upon plants--thus providing another example of how living things may interact with their environment.

In this Activity still another example of the interaction of living things with their environment is investigated: Collections of woodland litter are examined for the presence of animal life and evidence of its interaction with other components of the litter environment. The larger animal specimens are removed from the litter and examined. The litter is then subjected to conditions that change dramatically the environment to which the smaller animals remaining in the litter have become accustomed. As a consequence of their reaction to such environmental changes, they migrate into collecting bottles where they are examined.

MATERIALS AND EQUIPMENT:

1 hand trowel

1 roll of plastic tape

1 pint (500 ml) of rubbing alcohol

microscopes, 40x, one for every three or four children if possible, and slides

1 box of toothpicks

For each group of three or four children:

1 plastic bag of woodland litter. Bags should be

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	approximately one gallon capacity (See Preparation for Teaching)
3	magnifying glasses
2	popsicle sticks
1	double sheet of newspaper
1	thermometer, -20°C to 50°C
1	cardboard box, approximately 8 in. x 8 in. x 8 in. (20 cm x 20 cm x 20 cm)
1	12-in. (30-cm) ruler
1	Gooseneck lamp, or its equivalent, containing a 100W bulb
1	funnel, 5 in. (13 cm) top diameter, or its equivalent
1	screen, 14-in. mesh, or wire gauze, 5 in. x 5 in. (12 cm x 12 cm)
1	sheet of black construction paper, 8-1/2 in. x 11 in. (21 cm x 27 cm)
1	baby-food jar
1	aluminum pan, 4 in. (10 cm) diameter
1	pair of scissors
1	paring knife
5	3 in. x 5 in. (5 cm x 13 cm) cards

PREPARATION FOR TEACHING:

In preparing for Section 1, locate a wooded area where there are decaying leaves, rotting wood, and other such woodland litter on the ground. Such a wooded area need not be very large. Suitable areas can usually be found even in urban parks. Soon after a rain, visit the woodland area and collect 10 bags of moist litter, or about 10 gallons. A trowel may be used to dig up the litter; however, it should be sufficiently loose so that you can dig it up with your hands. Be sure that you dig it up to a depth of at least 4 inches. There may be a few low plants growing in the litter. Sufficient litter should be put into each bag to fill it about one-third full. When the bags are returned to the classroom, the litter should be sprinkled with water and the bags stored in a large cardboard box away from the light.

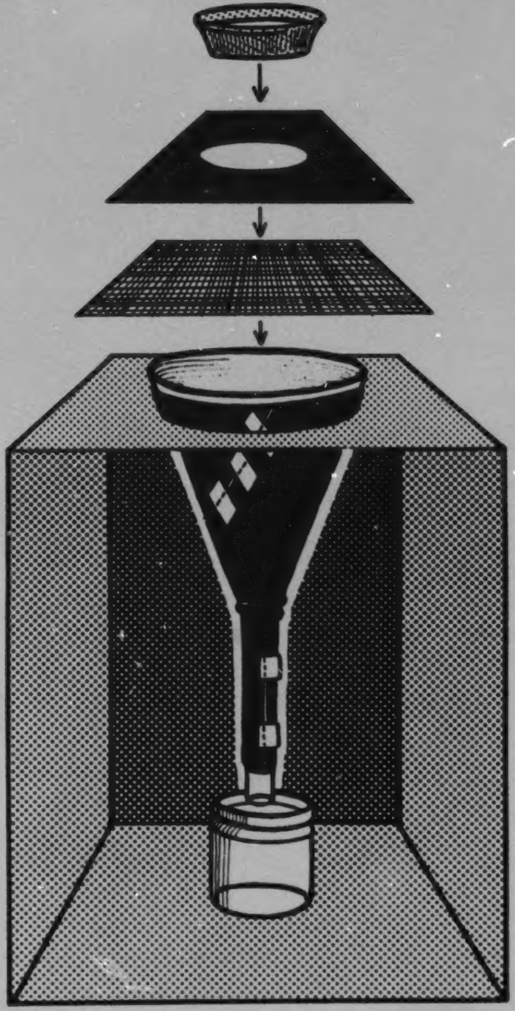
If litter should show signs of drying out before you are ready to use it, add as much as a cup of water to each bag and let it sit for a day or two. It is very important that the litter be moist when examined by the children.

In preparing for Section 2 encourage the children to assist in collecting the cardboard boxes after you have shown them one with the approximate desired dimensions. Make a display insect trap from one of the boxes by following these instructions:

Lay a box on its side so that the open side faces you. In the center of the upper side of the box draw a circle 4 inches in diameter. This can be done with a compass or by using a pencil to punch two holes, 2 inches apart, in a 3-in. x 5-in. card. With one pencil hold one hole over the center of the side of the box. Put the point of a second pencil through the other hole and draw a circle around the first hole as its center.

With a paring knife cut the circle out of the box. You now have a hole which can be used to support the funnel when it is placed into it. Cut a 5-inch square out of the black construction paper and lay it aside. Cover the outside of the funnel with the remainder of the construction paper, so that no light will enter the funnel from its side. Use the plastic tape to attach the paper to the outside of the funnel. Now insert the funnel into the hole. Put a screen on top of the funnel.

Now draw a circle, 3 inches in diameter, on the 5-inch square of black construction paper. After the circle is drawn, carefully cut it out without cutting through any sides of the square. Lay the square of construction paper, with the hole in its center, on top of



the screen. Cut the bottom out of one of the 4-inch aluminum pans and place it over the circle in the black paper. Put a baby-food jar under the end of the funnel. Arrange the gooseneck lamp so that the bulb is about 4 to 5 inches above the pan.

When a handful of woodland litter is placed into the bottomless pan on the screen, and the light turned on, small insects will move downward, away from the light and heat. As they move away from the heat and light they will fall through the screen, into the funnel and then into the baby-food jar. About one inch of alcohol should be put into the jar. This will kill the insects and make it possible to examine them later. To prevent stray insects from flying into the jar, cover it with a card. The card should have a hole in it large enough for the funnel tube to enter.

ALLOCATION OF TIME:

This Activity should take a minimum of two hours of class time.

TEACHING SEQUENCE	COMMENTARY
1. You might introduce this Activity by asking the children where they would go to hunt wild animals.	Encourage them to suggest as many places as they can imagine. Some will undoubtedly say that they would go to the woods.
When the woods are mentioned as a place to hunt wild animals, ask where they would look for the wild animals in the woods.	Again encourage them to think of all the places they might look. They will probably mention such places as in trees or caves, behind rocks, in holes, under dead logs, and under bushes.
Pour out one bagful of litter onto a sheet of newspaper on one of the tables. Invite the children to take a close look at it.	After you pour it out, pick up a handful and then let it fall back onto the pile.
Ask if anyone can tell where you obtained this material. If no one can tell where you got it, explain that you obtained it from the ground in the woods. Tell them that it	Forest litter is produced by

TEACHING SEQUENCE

is called woodland or forest litter.

Arrange the class into working groups of three or four each. Give each group the following materials:

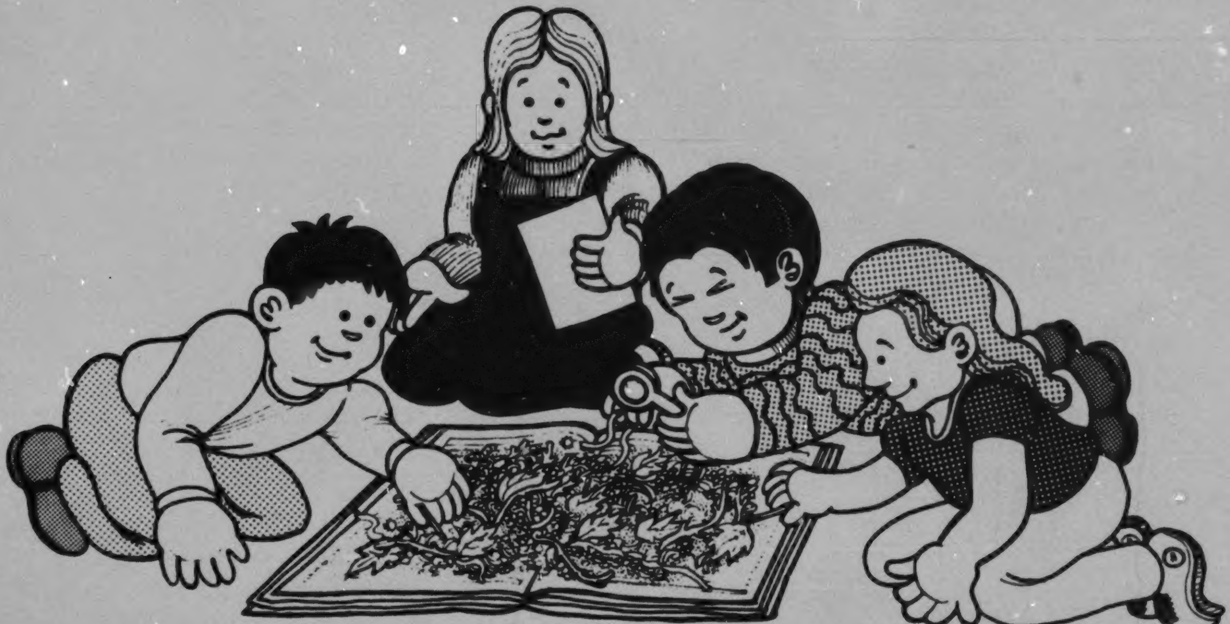
1	bag of litter
3	magnifying glasses
1	baby-food jar
4	toothpicks
2	popsicle sticks
1	double sheet of newspaper
1	thermometer

Invite them to go on a small-animal hunt through the litter. Have them carefully stack the litter in one mound on a double sheet of newspaper.

COMMENTARY

all of the wildlife--both plants and animals--that inhabit the woods.

The litter should be carefully emptied from the bag in the same condition as it was in the bag. It should not be mixed up or scattered over the paper.



TEACHING SEQUENCE	COMMENTARY
Ask them to describe their mounds of litter as an environment for small animals. Suggest that they use their thermometers to check the temperature inside the mound. Caution them about disturbing the mound of litter.	They should recognize the following properties of the mounds of litter: It is made up of organic material primarily from different parts and different kind of plants. It is moist. It may be assumed that it is dark inside the mound. It is cooler inside the mound than it is outside.
• Do you observe any animals outside the mound?	There will be relatively few or none that can be seen.
• Where would you expect most of the animals to be?	The animals are probably inside the mound of litter.
Have the children spread the litter into a relatively thin layer on their sheets of newspaper. Instruct them to examine carefully all parts of the litter for small animals. As they find them, encourage them to describe the animals. Have them put the animals in the jar. (They should keep the lids on.)	The litter should be spread into a layer no deeper than 1/4 inch. They should use toothpicks and the popsicle sticks to separate parts of the litter in their search for animals. They should use their magnifying glasses to observe animals as they are found.
	Some animals such as earthworms, ants, centipedes, beetles, and spiders children may be able to identify on their own.
As they search for small animals in the litter, ask them to look for any evidence they can that animals have been causing changes in the material making up the litter.	Small pieces of dead trees will have holes in them. These were probably made by insects. It should be possible to see where leaves have been partially eaten by insects. It may even be possible to observe ants or other insects carrying bits of material. It would appear that animals, as they live in litter, are slowly reducing the size of its particles. In time these will become a part of the soil beneath the litter.
Now ask how the litter, in turn, may have caused changes in the animals.	Although it cannot actually be observed, the animals have grown and increased in number as one result of using

TEACHING SEQUENCE

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material from the litter as food. As these processes have gone on, the animals have released carbon dioxide into the air, which permeates the litter, and discharged their excrement, which becomes part of the solid material within the litter environment. In these ways, animals and litter have been interacting.

After those animals that are easily picked out have been captured and put into jars, ask if anyone found evidence of animals that were too small to pick out.

They will undoubtedly have seen little worm-like and insect-like animals that were too small to pick up.

Tell them that they will need to use a special kind of small animal trap to catch the tiny ones. While they prepare the trap, they should return each pile of litter to the plastic bag, sprinkle the litter well with water, tie the bag, and return it to the large cardboard box.

As much as one cup of water may be used to make sure that the litter is soaked through before it is set aside for later examination. Remind the children that the litter was moist when they removed it from the bag. It will have dried out considerably during the time it was spread over the sheet of newspaper. By adding water you are attempting to return the litter environment to its original condition.

2. Use one class session to survey the collections of small animals that children found in their initial examination of the litter. Make a list of the different kinds found. This may be done by actually naming them, if

If you or any of the children know someone who can identify any of the animals, invite them to assist with this class session. Such a person may

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possible, and assigning different children the task of sketching each animal on a separate 3-in. x 5-in. card. They can then categorize them on the basis of their observations. The names and sketches of the animals should be displayed in some prominent place in the classroom.

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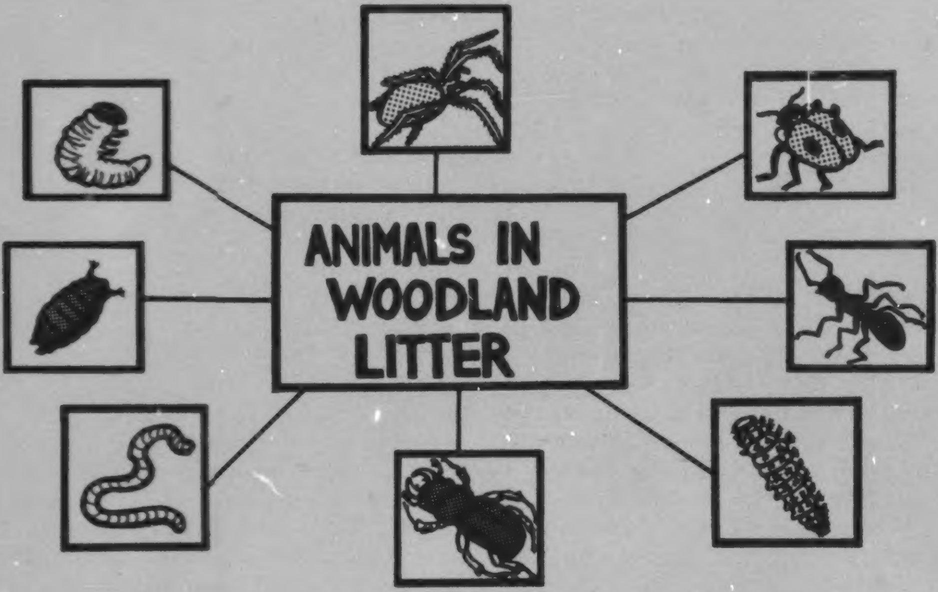
also bring along books containing pictures of the small animals.

A bulletin board display might be arranged.



3. Display for the children the insect trap you constructed.

Demonstrate how it is used. You may find it helpful to show them, step by step, how you made the display model.

The display should include the gooseneck lamp and alcohol in the jar.

Before putting the jar of alcohol under the funnel, place a handful of litter in the aluminum pan over the screen. After inserting a thermometer into the litter, record its temperature. Leave the thermometer in place. (If the jar is put in place before the litter is placed upon the screen and the thermometer inserted, small pieces of

TEACHING SEQUENCE	COMMENTARY
	material are likely to fall into the jar.) Now place the jar of alcohol into position, but do not turn the light on just yet.
• What are the properties of a litter environment?	These properties are listed in the commentary on page 98: made up of organic material moist inside dark inside relatively cool inside (recheck the temperature by reading the thermometer.)
• What other property could now be added?	Contains small animals.
• What do you suppose would happen if the properties of the litter environment were greatly changed?	The animals would probably move out or die.
• In what ways are the properties of the litter environment changed when the lamp above the small-animal trap is turned on?	As you ask this question, turn the lamp on. The litter then will receive more intense radiant energy. As the litter absorbs this energy, its temperature will rise. (Verify this by checking the thermometer reading.) The litter also dries out.
• In what direction will these changes be taking place?	From the top down.
• In which direction will the small animals in the litter probably move?	Downward into the jar of alcohol.
Give each group of children the necessary materials to use in constructing their own insect trap. After the traps have been constructed, have the children use them in collecting the smaller animals from the litter in their bags. They should put about 1/2 inch of alcohol in their jars.	Each handful of litter should be left on the trap for at least one day. If the entire bag of litter is to be searched for smaller animals, it will take about one week. After each handful of litter is

TEACHING SEQUENCE	COMMENTARY
	removed, the remaining litter should be sprinkled lightly with water.
4. Follow a procedure similar to that earlier and conduct a survey of the collections of smaller animals that came out of the litter and were trapped in the alcohol.	Most of them will be so small that it will be desirable to use the 40x microscope to examine them. Again encourage the children to sketch and categorize the tiny animals based on their observations.
5. Below are some important concepts that should have been learned in this Activity. One way to review the concepts is to ask questions that direct children's thinking toward them.	
• What is woodland litter?	Woodland litter is made up primarily of the parts of plants that live in the woodland.
• When is woodland litter being formed?	Woodland litter is being formed all the time.
• Why are there small animals in woodland litter?	Woodland litter appears to be a suitable environment for certain kinds of small animals.
• What are the properties of a suitable litter environment for small animals?	Darkness, a cool temperature, and moisture make an environment suitable for small animals found in woodland litter.
• What happesn to the litter when a lighted bulb is placed above it?	When the litter environment is exposed to radiant energy from the lamp, its temperature rises, water evaporates, and the small inhabitants move out.
• How do small animals interact with a woodland litter environment?	Small animals interact with a woodland environment by using parts of it for food and the food, in turn, contributes to their growth.

EXTENDED EXPERIENCES:

1. A field trip into a wooded area will add greatly to the concepts developed in this Activity. Encourage the children to assist in planning the field trip. Here are some questions that may be helpful in planning what to look for:

- What different kinds of larger plants and animals can be found living in the woods? These may include different kinds of birds, mammals (squirrels, etc.) reptiles (snakes), amphibians (frogs), insects, trees, bushes, low-growing plants.

- How can you find the names of the different kinds of living things? You may be able to have someone accompany you who can identify many of them. You might also have books in the library that would help. The following books are picture guides written by Herbert Zim, and others, and published by Simon and Schuster: Birds, Flowers, Insects, Reptiles and Amphibians, and Trees. In preparation for the trip, committees of children might be assigned the task of acquainting themselves with these books.

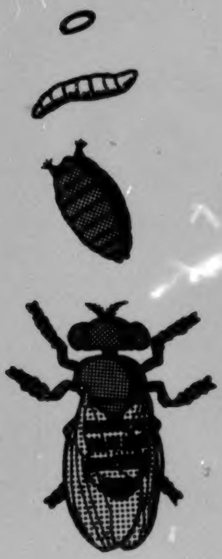
- What additional evidence can be found that the plants and animals living in the woods are interacting with their environment? They should find fungi of various kinds growing on dead trunks and branches of trees. Fungi are simple plants which do not contain chlorophyll. There are many different kinds of fungi. Bread mold is a common one. Mushrooms and toad stools are others. Dead trees generally have large shelf fungi growing on and inside of them. The fungi cause the decay of the dead tree and it, in turn, supplies food for the fungi. Birds and squirrels may be seen in bushes and trees eating seeds, nuts, or insects. If rocks or logs are rolled over, many insects will be seen scampering in all directions.

- How do the trees affect the environment within the woods? During the summer, they shade the woodland floor. Therefore, you will see few of the kinds of plants that grow well on unshaded plots. Trees are constantly added to the woodland litter. They also break the impact of heavy rains. Their roots keep the earth beneath them relatively porous. In these ways they prevent soil from washing away after heavy rains.

2. The environment within woodland litter may be referred to as a microenvironment, because it is a small part of a larger woodland environment. After discussing the idea of microenvironments, encourage children to locate other ones. Such places as the following may be considered microenvironments: a lawn from the soil surface to the tips of blades of grass; the north side of a house; the area beneath a bush; the denuded

ground around an ant hill; the narrow space between two buildings; a flower box; and a hole in the ground. In each of these places air temperature, relative humidity, amount of sunlight, moisture, and the living things that inhabit it will be, in one or more ways, noticeably different from the larger environment within which it is located.

Children can create microenvironments, populate them with living things, and observe how the living things interact with such encapsulated environments. Bread mold may be started on a slice of bread, in a see-through container. If a small jar of water is also placed in the container and the container covered with a plastic wrap, the mold will grow very rapidly. Mold that has just begun to grow on fruit can be caused to grow more rapidly if it is kept in such an enclosure. However, with fruit it would not be necessary to include a jar of water since there is sufficient moisture in the fruit to maintain an environment with high relative humidity.



3. A very interesting project is to make a fruit-fly farm. As the name implies, fruit flies are generally found around rotting or fermenting fruit. Fruit flies are insects that go through several stages in their development--from a fertilized egg laid by a female fruit fly to an adult fly. After the egg is laid, it takes only a few days for it to hatch into a small worm-like creature called a *larva* (or maggot). The larva consumes relatively large amounts of food and grows very rapidly. In several more days the larva encases itself in a relatively hard little case and is called a *pupa*. After a few days of development as a pupa, a full-grown fruit fly emerges. This entire process of development takes less than 2 weeks. Children can observe generation after generation taking place in a fruit-fly farm.

Before starting the farm children will need a see-through plastic container. An excellent one for this purpose is the container that florists use in delivering corsages. These have a hinged lid that can easily be sealed with plastic tape. An appropriate size is one that is about 9 inches long, 6 inches wide and 5 inches high.

An overly ripe banana can easily be obtained from a fruit market. The likelihood of fruit flies having already laid eggs on the soggy banana are very good. However, this can be checked by placing the banana into the container, closing it, and putting it in a part of the room that is out of direct sunlight. Under such conditions it is almost certain that a first generation of adult flies will develop within a few days. If by chance none appear within two weeks, the container should be left open for a few days. The distinctive odor of the ripened banana will surely attract a number of starter flies. Once there is an established population, the lid of the container should be sealed with scotch tape. A microenvironment, including air, a banana, and fruit flies, has been created. The banana is a source of food for flies. It contains sufficient water to keep moisture in the environment. Even though the container is sealed with plastic tape, in all likelihood the seal will not be airtight. There will be sufficient exchange of air with the room to maintain the flies for as long as the banana supplies them with food.

To observe details within their fruit-fly farm, the children should use magnifying glasses. When observing the container it should be held in various positions relative to a light source in order to see clearly such objects as the following:

adult flies, their bodies, wings, legs and antennae
eggs, after being laid and as they are hatching
larvae, from freshly hatched small ones to large ones about ready to pupate
pupae, freshly formed as well as those from which the adult flies are beginning to emerge

From week to week, the fruit-fly farm should be observed by children to note any observable changes in the interaction between fruit flies and their environment. Questions such as these could be used to direct their observations:

- Does the banana appear to be getting smaller?

- Are other living things, such as molds, finding this environment a suitable one?

- Does the number of flies in the fruit-fly population appear to be changing?

- What happens to fruit fly activity when the container is placed on ice cubes?

- What do you think about the relative humidity in the container?

In one such farm, over a period of six weeks, the banana appeared to be getting smaller. There was a good deal of brown liquid around the banana. No other living things, besides the banana and fruit flies, were observed. The number of fruit flies appeared to be approximately the same from week to week. Numerous dead flies could be observed in different parts of the container. When the container was cooled by putting it on ice for a period of time, movement of the fruit flies appeared to be less. As indicated by deposits of liquid on the lid and walls of the container, the relative humidity remained high over most of the six-week period.

It is recommended that each group of children who start a fruit-fly farm keep it for as long as flies can survive within it. If records are kept of such changes as the above, children will have a better concept of how living things interact with their environment, and how living things may eventually change the environment so that they can no longer live in it.

Minisequence II
Heat Energy and Hydrate Bonds

The Minisequences in Grade 6, for the most part, serve as culminating experiences in developing the five conceptual schemes selected for the COPES curriculum. Observations on living systems and their environment in Minisequence I were used to develop further the concepts within the scheme Interaction and Change. The Conservation of Energy conceptual scheme has been developed along two major lines--conservation of heat energy and conservation of energy in mechanical systems. Minisequence II of Grade 6 is intended as a culmination of the heat energy story towards which specific Minisequences in Grades 3, 4, and 5 were directed. (Minisequence VI will deal with conservation of energy in mechanical systems.)

The storyline started in Grade 4 with the concept of the heat energy unit (h.e.u.) as a measure of thermal energy which could be used to keep track of this energy when samples of water were mixed. Subsequently, in a series of Activities concerned with the role of thermal energy and change of state, children observed the "disappearance" of the measured heat energy of a sample of water when mixed with its solid--a piece of ice. A model was developed to help account for this absorption of thermal energy during the melting of a solid. According to this model, the absorbed heat energy was used to free molecules from binding forces holding them in the fixed patterned array characteristic of a solid structure. The freed molecules of the liquid were inferred to possess more energy than those in the solid by virtue of the energy absorbed to form the melt. Change of state was further extended to the observation that heat energy also had to be absorbed by the molecules in a liquid in order to free them from any bonds holding them to neighboring molecules--resulting in completely free molecules in a gas. Similarly, they observed that to change a gas back to a liquid, and a liquid back to a solid, heat energy had to be removed. Thus the liquid was considered to be in a higher energy state than the solid, and the gas to be in a still higher energy state. To change from one state to a higher energy state requires the addition of (thermal) energy, which serves to break the bonds holding the molecules in position. Conversely, to go from a higher to a lower energy state (e.g., liquid to solid) involves removing thermal energy so that the bonds can re-form. In Grade 5, Minisequence III, these concepts were extended to the solution process which involves the breaking up of solids (dissolving) by placing them in suitable liquids. In this process, as in melting, it was found that the molecules of the solid absorb heat energy as they are freed from their fixed positions (i.e., their bonds are broken). In dissolving, however, the necessary heat energy is taken from the solvent, rather than supplied from outside the system.

The present Minisequence will again be concerned mainly with overcoming bonds in solids but with a very distinct difference. In melting and dissolving, where freely flowing liquids are formed, the bonds holding the units of matter in the structure exist throughout the solid--one unit may be held by several bonds, each one holding it to a neighboring unit in a particular direction. Here we will consider another type of bond--a chemical bond. This bond is directed between two units of matter, either two atoms or two molecules. Chemical bonds can vary in strength between extreme values: a moderate amount of energy can break the bond between units of water and of copper sulfate, while extremely large amounts of energy, not available in the laboratory unless one resorted to electrolysis, would be needed to break the bonds holding the units of hydrogen atoms and oxygen atoms within the molecule of water.

The bond between units of water and of copper sulfate is called a hydrate bond. The experiences in this Minisequence will extend the concept of energy and bonds to the specific chemical bond between certain salts and water molecules, known as a hydrate bond, and subsequently to another example of such chemical bonds. Blue vitriol, known chemically as the hydrated form of copper sulfate, is one hydrated salt which the children will investigate.* As the name implies, the color of the hydrated salt is blue; the anhydrous form is white. Thus the bonded water changes the properties of the solid salt--the color is no longer blue. A great many salts are found in both hydrated and anhydrous forms; however, there need not be differences in color between the two. Epsom salt (magnesium sulfate)** is white in both its hydrated and anhydrous forms. Again the children will find that energy must be absorbed (by the hydrates) to break the bonds; and when the bonds re-form, this energy is released. Using the model of bond formation (or breaking) developed in earlier grades, they are able to infer that the dehydrated salt is at a higher energy state than the salt with its water bonded to it since the solid has to absorb energy to break these bonds. This additional energy is released when the bond to water is re-formed. Thus the purposes of this Minisequence are first to introduce another type of bond found between units of matter and to reinforce the concepts introduced earlier that the breaking of a bond requires the absorption of energy and that energy will be released when the reverse takes place. It is further reinforced that the substance formed as a result of the absorption of energy, whether a liquid, gas or anhydrous salt and water, will be at a higher energy state, or level, than the corresponding solid, liquid, hydrate, etc.

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*Chemical formulas are often used to represent the composition of the salt with its bonded water. Thus, blue vitriol is written as $CuSO_4 \cdot 5H_2O$. This indicates that there are 5 molecules of water bonded at specific sites on the $CuSO_4$ (copper sulfate) molecule. The chemical formula of the white anhydrous form is simply $CuSO_4$. Note that copper sulfate throughout this Minisequence is referred to with the children as blue vitriol only. The chemical name is not used. In the next Minisequence, the children discover that copper is a component unit of blue vitriol.

**The formulas of the hydrated and anhydrous forms of epsom salt would be $MgSO_4 \cdot 7H_2O$ and $MgSO_4$ respectively. In the hydrated form there are 7 molecules of water bonded to each molecule of magnesium sulfate.

The first Activity is a review of the effect of heat energy as the children observe the ability of different heat sources to melt several solids. Then heat energy is added to two solids which do not behave in the usual manner--table sugar and blue vitriol. Both change color, but whereas the former also melts, the latter does not. Are these reversible changes? In the case of the simple melts, the children see that as heat energy was removed the solid state re-formed. They find that cooling the sugar and copper sulfate does not bring back the original conditions. Thus they are led to infer that different types of interaction may be taking place there.

In the second Activity they investigate the interaction of heat energy and blue vitriol still further. They observe under the conditions of the experiment in this Activity that, as the blue color disappears on heating, droplets of a colorless liquid appear in the cooler portions of the system. They discover that the colorless liquid is water because only when water is returned to the system does the blue vitriol re-form; and when it does so, it is with the release of heat energy. They observe the same type of interaction with epsom salt which does not change color on dehydration. They can then relate the interaction with energy to the removal of bonded water rather than to any change of state.

A model of what might be happening at the molecular level is developed in Activity 3. By means of a marble model, the children are led to conceptualize the bonding of water molecules to a salt with none of the characteristics of free water. Upon the addition of heat energy, these bonds are severed and water is lost from the system. The model also explains the similar behaviors of other hydrated salts, only some of which may undergo changes in color. In addition, they are helped to relate these concepts to observations on the release or absorption of heat energy as different salts dissolve in water. Their earlier experiences in Grade 5 exposed them only to salts which absorbed heat energy from the water as they dissolved--that is, the solutions cooled down. Now they make use of the model of hydrate bond formation to infer that when a salt dissolves in water accompanied by a release of heat energy, it is likely that hydrate bonds are forming between the salt and water. Energy is given off as bonds form. But salts cooling down on dissolving in water would signal that hydrate bonds may already be formed and heat energy is being absorbed as the bonds holding the units together in the solid are broken.

In the last Activity the concept that heat energy is involved in any bond breakage is further generalized by examining a different kind of chemical bond--that between molecules of starch and molecules of iodine. When the bond is present, a characteristic deep blue color is exhibited. This color is used as a test for the presence of starch as the children found in Grade 3. The children now find that adding heat energy to the deep blue starch-iodine complex results in a loss of the color; the bond has been severed. On cooling (removing the heat energy), the bond re-forms with a return of the deep blue complex. Thus observations and conceptual model building on the interaction between heat energy and blue vitriol eventually lead to a more generalized understanding of the structure of more complex molecules.

The concepts developed in this sequence are as follows:

1. Heat energy that is absorbed by an apparently dry solid salt may drive off water molecules that were bonded to the salt molecules.

2. The bonds between water molecules and the salt molecules in a crystalline structure may be broken when heat energy is absorbed.

3. The heat energy that is absorbed (used) to break bonds holding water molecules in a hydrated salt will be released when the bonds re-form.

4. When solid salts interact with water to form a solution, the temperature may increase if hydrate bonds form during the interaction.

5. When solid salts interact with water to form a solution, the temperature will decrease if hydrate bonds do not form (or are already formed) and heat energy is absorbed in breaking the bonds holding the molecules within the solid structure.

6. The anhydrous form of a solid salt (the salt minus its bonded water molecules) possesses more energy than the hydrated form (the salt with the bonded water). This extra energy is given off in the form of heat energy when the hydrate bonds are formed.

Activity 1 Interaction of Heat Energy with Solids

Very early in the COPES curriculum children were introduced to the concept that something we call heat energy can interact with matter in several ways. One way is to cause a change of state, such as that from a solid to a liquid. Here children will review differences in the ability of certain heat energy sources to melt some solids. They will classify a series of solids based on this observation and relate these differences to differences in the strength of the bonds between the molecules, or units of matter, holding them in position in the solid. In the melting process the added heat energy allows the molecules to be freed from these bonds to become part of the more mobile molecules of the liquid melt. The heat energy absorbed by the molecules as they become part of the melt is present in the more energetic molecules within the liquid. Thus, the concept that a liquid possesses more energy than its solid by virtue of the change of state is reintroduced and will be used in subsequent Activities as children consider other results of heat energy absorption. Children will also focus their attention again on the reversible nature of this interaction. Removal of heat energy from a melt results in bonds re-forming as a solid again appears. It is inferred that the solids which cannot be melted by the heat sources must have extremely strong binding forces holding the molecules in place.

This review prepares the children for introduction to another kind of interaction as heat energy interacts with sugar crystals and with blue vitriol crystals. In the former, after the melt has been produced, there appears a change in color; in the latter, the addition of heat energy results in a loss of color--the blue crystals turn white. However, no melting takes place. Thus, the children are presented with a dilemma; when some of the melts lose heat energy as they cool down, the original solid re-forms. However, not only does blue vitriol not melt, but upon cooling the colorless substance they observe no return of the blue solid. Is this process reversible? Just what can this interaction involve? In subsequent Activities the children attempt to find the answer to these questions.

MATERIALS AND EQUIPMENT:

For the class:

several (at least 7) wide, squat containers to serve as sources of chemical supply, e.g., cottage cheese containers

	several narrow wooden dispensers such as popsicle sticks, beverage stirrers, etc.
	plastic wrap
3	polyfoam cups, 6- to 8-oz
1/2	cupful of ice chips
	safety matches
2	polyfoam containers, 3 qt (3 liter) capacity, unless hot tap water is available in the classroom
	several jars, empty, which can fit into the polyfoam cups, e.g. a 4-oz baby food jar (optional--see Preparation for Teaching)
	supply of the following chemicals: (about 1/2 cup of each)
	salol (phenyl salicylate)
	table salt (sodium chloride)
	sugar (sucrose)
	blue vitriol [copper (cupric) sulfate, hydrated blue crystals]*
30	marbles of the same size and color
	cement, 2-part epoxy
	double-sided masking tape, or carpet tape
	cardboard square, about 6 in. on a side
1	shallow dish, e.g., a petri dish, glass or plastic

For each child or group of children:

1	candle
2	polyfoam cups, 6- to 8-oz
5	aluminum foil muffin cup liners or 3 in. by 3 in. (7.5 cm by 7.5 cm) pieces of aluminum foil
1	test tube holder, metal
1	magnifying glass

*You will probably need to obtain this substance from a chemical supply house. For all these Activities the crystals should be fine. Therefore, request ACS (American Chemical Society) or Reagent grade, rather than technical grade. Technical grade copper sulfate usually is in the form of large clumps, which are unsuitable.

PREPARATION FOR TEACHING:

Have some 50°C water available in the polyfoam containers. If you have hot tap water and children have access to it, you may want them to obtain their hot water supply at the sink.

Nest one polyfoam cup in another to provide better thermal insulation and half fill this with some chips of ice. Invert the third polyfoam cup on top as a cover.

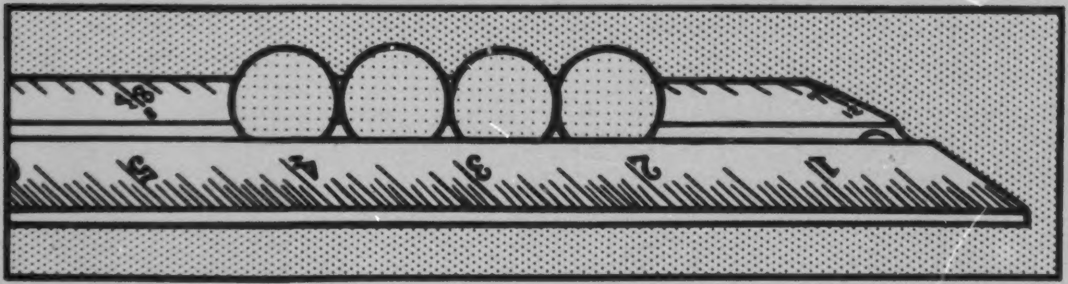
When you are ready to begin Section 1, put the ice, salol, and the table salt in the wide containers. About 1/4 cup in each container will be sufficient. For ease of access by the children, you may want to set up more than one container for each chemical. Next to each container place several wooden splints or popsicle sticks. These will serve as dispensers. Before class, have some children assist in marking the dispensers with a line about one centimeter up from one end. One measure of solid will be that amount which can be picked up on the marked end of the wooden stick. Drinking straws can also be used as dispensers: simply flatten a 1-cm length of the end to form a small spatula.

The children will be placing some of each chemical in an aluminum "boat" in this investigation. They can use the metal foil liners sold with muffin cups or they can make their own as follows: Press a piece of aluminum foil around the base of a jar which can fit into a polyfoam cup. A 4-oz baby food jar is ideal. Leave enough foil extending up so that it can be picked up with a test tube holder. Also, there should be no seams at the edges through which water can seep.

For Section 2, again have hot (50°C) water available either in the polyfoam container or at the tap. Using one or several squat containers for each chemical, set out about 1/4 cup of the following: sugar (sucrose), and fine crystals of blue vitriol (copper sulfate). Cover the containers with plastic wrap during the time the children are not getting their supplies and place the different substances in different locations to avoid possible contamination. Place several marked (1 cm) clean wooden dispensers next to each container. Label the containers with the common name of the substance.

Also, put out the supplies of candles, aluminum foil, test tube holders, polyfoam cups and magnifiers where the children can help themselves. Metal test tube holders are called for instead of a wooden clamp substitute because in a later Activity they will be using it over a more intense heat source which might affect the wood.

Activity 3 calls for a marble model of a solid to be used in the discussion of bonds--more specifically the chemical bond between a water molecule and copper sulfate. This model should be made up ahead of the time you expect to use it. The instructions for its preparation are very similar to those given in Grade 4, Minisequence V, Activity 2. Marbles and epoxy cement can be used to make the model. There are two parts to all epoxy cements: (1) the hardener and (2) the resin. Squeeze out equal amounts of each on a clean surface. It is convenient to mix the two parts with a toothpick or wooden match stick in one of the aluminum foil "boats." (The wooden mixer can also be used as the applicator.) Mix them together thoroughly until you get a uniform color. Mix only the amount that will be needed. When finished, allow the unused epoxy to harden and then discard both the dish and the toothpick. Drying time at normal room temperatures is 1 hour but you will need to leave the models overnight for a more permanent bond.



The first part of the model can be made by cementing together four rows or marbles, each row containing four marbles of the same color and size. A larger model can be made--for instance, a 5-marble by 5-marble square--but preferably not a smaller one. Cement each row separately. This can be done by placing each row in the groove of a ruler as shown in the illustration and applying a small bit of epoxy (with the toothpick) between each marble. Be sure that all marbles are in contact.

Make 4 of the rows and allow the epoxy to set at least overnight. Then cement the rows together to make the square. The rows can be held in position for support and ease of handling while the epoxy is hardening by setting them on the sticky surface of a mat which has been made by sticking double-sided masking tape to a piece of cardboard.

The model described above represents a highly ordered arrangement of units in a solid such as the crystals they are observing. Let 6 to 10 additional marbles remain loose in a shallow dish to represent the mobile molecules of a liquid.

ALLOCATION OF TIME:

The children will need about 1-1/2 hours to complete this Activity but you may want to allocate more or less time depending on the amount of review you feel is necessary.

TEACHING SEQUENCE

1. Have the children get three of the aluminum foil "boats", go to the supply, and place "one measure" of ice

COMMENTARY

The first part of this Activity is meant to provide a review of concepts introduced in Grade 4 and expanded in Grade 5 concerning the role of heat energy and the liquefying process. In this sequence we will focus our attention on what happens to solids as heat energy alone is added to the system. Thus we will be concerned, initially, with the melting of a solid and not with the dissolving process (where water is added to the system).

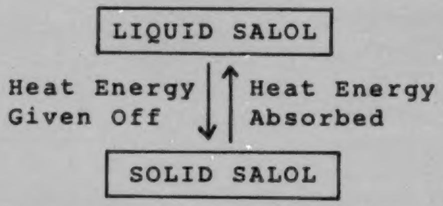
The intent is to review the concepts introduced in Grades 4 and 5 that solids are held together by binding forces between the smallest units in the substance, the molecules, and that the size of these forces varies among different substances. In addition, attention will be focused on the reversible nature of the melting process. Pace yourself in this review depending on the needs of the children. You may want to refer to the introductory Activity of Minisequence III of Grade 5 and to "Change of State" in Grade 4.

These boats may be muffin-cup liners or they can be made

TEACHING SEQUENCE	COMMENTARY
chips in one, one measure of table salt in another, and one measure of salol in the third.	from aluminum foil as described in the Preparation for Teaching.
	A "unit measure" is that amount which can be picked up on 1 cm of the wooden dispenser.
They should place the three boats at their work areas and observe them.	
• Is anything happening to the solids?	Only the ice shows signs of an interaction--it appears to be liquefying.
• What is causing the ice to become a liquid?	It takes heat energy to break the bonds of a solid.
• Where did the heat energy come from to cause the ice to liquefy?	From the surroundings, the air, the pan the ice is sitting in, etc.
• Are there any signs that an interaction is taking place in the other two solids?	Encourage them to observe these solids carefully with their magnifiers. When they can measure (or otherwise detect) a change in a property, they can be certain that some interaction is taking place. There does not seem to be any interaction taking place in these two substances.
• What can you say about the bonds holding the solid together in ice as compared with these other two solids?	The bonds must be weaker in ice, since the heat energy available from the room could liquefy it, but not the salt or salol.
Show the children the supply of hot water and suggest that, since it is a more efficient source of heat energy than the air in the room, they test the two solids over hot water to see if they might liquefy.	
Have each child take two polyfoam cups, nest one in the other and place in it about a	The temperature should be one

TEACHING SEQUENCE	COMMENTARY
half cupful of hot water.	that can be obtained from a hot water tap--about 50°C or above.
Set the aluminum boat with the salol on the hot water and carefully observe the contents of the boat.	The solid will start to melt and form clear globules of liquid salol.
This boat should then be set aside on a piece of foil while they repeat the procedure with the boat containing the table salt.	It may be necessary for them to get a fresh supply of hot water. They should observe no change in the appearance of the solid sodium chloride.
• Based on this observation, what can you say about the forces holding the solid structure together in salol compared with table salt?	From this observation they can conclude that heat energy transferred from the hot water was sufficient to break the binding forces holding salol together as a solid structure but not sufficient to overcome the binding forces in table salt.
The binding forces holding salol together are apparently weaker than those holding salt together and the forces holding ice together are weaker still.	This inference, that there are differences in bond strengths, was introduced in Grade 5 and will come up again later in this sequence.
• Where is the heat energy after the bonds have been broken?	The heat energy is in the more freely moving, mobile liquid.
As they discuss the situation, if the marble model is ready, show it to the class. Indicate that this is one way of representing the properties of a solid. Ask them to tell you in what way this model depicts a solid crystal structure.	Each marble, of course, represents a molecule making up the substance. Be sure they bring up such characteristics as the definite shape of a solid as well as the orderly array which might be thought to make up crystals.

TEACHING SEQUENCE	COMMENTARY
Display the loose marbles in the dish.	
• What could this be used to represent?	There is freedom to move about. Thus this model could represent a liquid, in which the molecules are more energetic.
Now direct their attention to the boat which had been set aside containing the salol.	
• What has been happening there? Feel it. What do you think is its temperature?	For one thing, the salol has cooled down. It is probably back to room temperature.
o Is it still a liquid?	It may still be liquid because it tends to have difficulty in reforming crystals from the melt.
• Once the temperature returns to that of the room, what state should it be in, liquid or solid, (as evidenced by what they started with)?	If the phenomenon is reversible, the liquid salol should revert to the solid, which is the state of matter one finds salol in at normal room temperature.
As they observe the liquid salol, have them drop a tiny crystal of salol on the drops of liquid. You might tell them they are "seeding" it.	Crystals should form almost immediately. At the same time, some children may be able to sense a slight rise in temperature. When a substance is still a liquid at a temperature when it normally would be a solid--that is, at a temperature below its melting point--it is referred to as "supercooled." (Children who have had the Grade 5 COPES experiences may see the analogy to a super-saturated solution. See Activity 4 of Minisequence III.) In both cases, seeding causes solids to form, with the release of the extra heat energy present in the supercooled liquid.

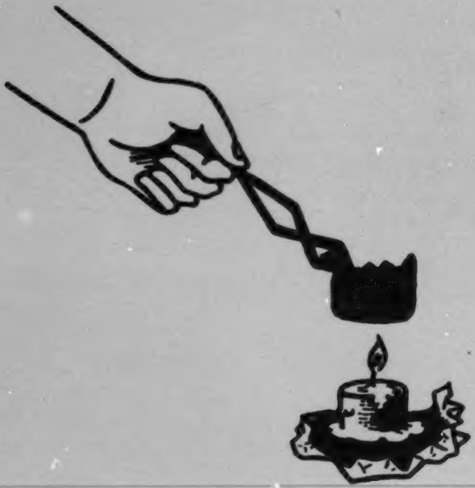
TEACHING SEQUENCE	COMMENTARY
What happened to the heat energy which the salol had absorbed when it liquefied? What happened to it as the salol solidified?	The system gave off heat energy to the surroundings. The air and container warmed up.
Discuss what was happening with the salol as heat energy was added and then given off. During the discussion, you might put a schematic diagram on the board to highlight what happens. This type of schematic will be used in subsequent Activities.	As heat energy was absorbed by the solid, a change of state occurred--the solid melted. Then when heat energy was removed, the liquid cooled down and eventually reverted to a solid. In other words, this interaction is reversible.
 LIQUID SALOL Heat Energy Given Off Heat Energy Absorbed SOLID SALOL	
• Is the interaction of heat energy with ice also reversible?	The children will undoubtedly suggest that water also can be made to revert to the solid state (ice) by removing heat energy.
	In the next Section of the Activity, the children will subject the table salt and other solids to an even greater source of heat energy, a candle flame, and look for signs of interaction. Remove the salol before starting this Section. Salol, if heated over such a flame, may smoke and ignite. Be sure the small samples the children have been working with are discarded in a trash basket. Since salol is insoluble in water, it should not be thrown into a sink. The water can be discarded also but the salt should be saved.
2. Two questions might arise	

TEACHING SEQUENCE	COMMENTARY
as a result of the children's previous observations: (1) If a hotter source of heat energy were applied to the salt, would it too liquefy? and (2) Would other solids than the ones they have tested also show a reversible interaction with heat energy? Suggest that they try putting the salt and two other solid substances over a candle flame and see what happens.	
Have the children obtain 2 more foil muffin-cup liners or make them out of additional squares of aluminum foil. Each child should place 2 measures of the sugar, and 2 measures of the blue vitriol into each of two boats.	They should still have the sample of table salt. Blue vitriol is the common name for copper sulfate and the common name should be used throughout the sequence and into the next, rather than the chemical name. The children will discover that copper is a structural unit of this substance in Minisequence III.
They should bring the boats and their contents back to the work area and place them on a sheet of paper. Encourage the children to observe the substance carefully with their magnifiers and describe their appearance.	Like the salt, the sugar crystals will be familiar to them. The blue vitriol also exhibits characteristics of crystals in that some will reflect light.
Next, they may want to find out if the two new substances will change if subjected to the temperature of hot water. If so, have them obtain a fresh supply of hot water. Then carefully place the boat containing each solid on the water and observe the contents.	They will observe no change in the appearance of the sugar. The intense blue color of the other substance may lighten very slightly. Neither will

TEACHING SEQUENCE

Have each child obtain the rest of the equipment that will be needed in this Activity. This should include a candle, an extra piece of foil on which to place the candle, and a test tube holder.

After the candles are set up, light each one and tell them to heat each chemical in its boat over the flame, one by one.



The foil boats should be held with the test tube holder, and the children should slowly move the boat over the flame. At frequent intervals have them remove the boat from the flame and carefully observe the contents.

COMMENTARY

liquefy.

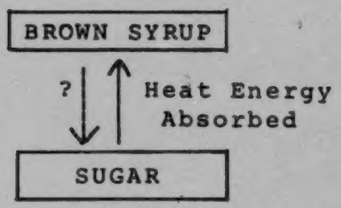
If the short, fat, food-warmer type candles are not used, longer candles can be inserted into a ball of plasticene which has been flattened out on two sides so it sits evenly on the table top. This serves as a convenient candle holder.

As the children start to work with the candles, be sure they have been alerted to all the precautions regarding working around flames.

1. Hair must be tied back, no loose strands.
2. No long or loose sleeves.
3. Do not stretch arms over the flame to get at an object.
4. The heat source should be placed in an area clear of books, papers, etc.
5. When the object or material being heated is to be observed, the children must bring it away from the flame to avoid leaning over it.

There will still be no apparent change in the salt. In the case of the sugar, however, there will be considerable changes: At first it will liquefy. Then the sugar will start to change color. It will become yellowish brown. If held over the flame too long, it may actually start to smoke and become black. Have the children remove the sugar from the flame as soon as they

TEACHING SEQUENCE	COMMENTARY
	observe a color change.
	As the blue vitriol crystals are being heated, the children will also notice a color change. The blue color disappears. It becomes lighter blue and eventually becomes very light--almost white.
Have the children set aside the foil boats one by one after they have been heated. Be sure each is identified.	They can place them on a sheet of paper after the boat has cooled off and write either the names or numbers next to each cup.
• Did the increased amount of heat energy coming into the boat cause the table salt to liquefy?	There was no change in its appearance. Some children may be alert to the fact that the temperature of the solid was raised. Heat energy was absorbed to accomplish this interaction but there was no change in state. It can be inferred that the binding forces in this substance are very strong.
• Did either of the other two solids liquefy?	Yes--the sugar formed a liquid.
• Did any other changes take place in the sugar?	The evidence for an interaction, as they should be aware, is a change in a property. In the case of sugar, it not only melted, it also changed color--it charred.
• Is the interaction of heat energy with sugar reversible? How could you find out?	They should suggest removing the added heat energy, as they did with salol.
Encourage them to try out their suggestions to see if the original state can be formed again. A schematic of what they have observed, so far, can be placed on the board:	By this time the foil boat will have been sitting at room temperature for a while. If it still feels warm, the cup and its contents can be placed in cool water in the polyfoam cup to bring it down to room temperature.

TEACHING SEQUENCE	COMMENTARY
	
They will find that this particular interaction cannot be reversed by merely reversing the procedure; it does not appear to be a two-way street as the other interactions were.	
Now focus attention on the contents of the last cup:	
• Did heat energy interact with the crystals of blue vitriol? What is the evidence?	Yes--the change in color (blue to white) is evidence of an interaction. The solid also changed from being in the form of crystals to being "powdery."
• Did you observe any melting? Were the binding forces broken?	Since the blue vitriol showed no signs of liquefying, it appears that the binding forces holding the solid in place are still in effect.
By now, the contents of the cup will probably have cooled down as much as they're going to. Cautiously ask them to feel the aluminum.	It will feel comfortable to the touch.
• What occurred as the system came back to the temperature of the room?	Heat energy was given up to the surroundings. The system returned to the temperature it was before heating started.
• Do the contents return to their original condition? Is the process reversible?	The solid still remains a whitish color, even on cooling off. (Don't let this system remain in the air too long, since it might pick up some moisture and become a faint blue--but not the deep blue of

TEACHING SEQUENCE

The blue vitriol did not liquefy on interacting with heat energy; it did change its color and appearance. What happened? Some children may be eager to develop hypotheses to explain the strange behavior of this solid. Encourage their speculations.

In conclusion help the children to summarize the different kinds of interactions that heat energy seems to have with solids.

1) It raises the temperature.

2) It produces a change in state (melting). When the heat energy is removed, the melting process is reversed; a solid re-forms.

3) It produces a change in state and sometimes a change in other properties (sugar charred).

4) It produces only a color change, accompanied by a slight change in the appearance of the solid.

COMMENTARY

the unheated substance.)

Activity 2 Water Out and Water In

As the children continue to investigate the interaction of heat energy and blue vitriol crystals, they find that under the conditions of the present Activity the loss of the blue color as heat energy is absorbed is accompanied by the appearance of droplets of a colorless liquid in the cooler portion of the system. Although the substance does not revert to its original condition on cooling, the blue color is returned when water is added to the system. Children find that water is the essential ingredient by investigating the effectiveness of other colorless liquids in causing the color to return. Furthermore, not only does the blue color return, but heat energy is liberated! The entire system becomes very hot as drops of cool water are added.

Thus the children infer that the absorption of heat energy by blue vitriol removes water from the crystal, called a hydrated crystal. Adding water results in the dehydrated (white) form of the substance returning to its original state, with the release of the absorbed heat energy. The heat energy used in the process of dehydrating the blue substance did not disappear but was present in the white substance and possibly also in the other product, water, which had gone off as a gas. Such color changes, however, are not a requirement of hydration, or of dehydration. This the children learn when they follow the same prodedure using a colorless hydrated salt, magnesium sulfate, more commonly known as epsom salt. The children are aware of the hydration when they again sense the release of heat energy as water is added to the colorless "dried" solid.

Apparently, then, the dehydrated form of these substances is at a higher "energy level" than the hydrated form. Thus the concept of relative difference in energy levels is now being related to two solid forms and not to a solid and its liquid (or a liquid and its gas), as in a change of state. The absorption and release of heat energy to accomplish all these changes is one of the criteria for such inferences. In the next Activity, they will develop a model of what might be happening at the molecular level which could explain these observations.

MATERIALS AND EQUIPMENT:

For the class:

plastic wrap

safety matches

1 container, polyfoam, 3 qt (3 liter) capacity

6 narrow wooden dispensers such as popsicle sticks, beverage stirrers, etc.

1/2 cup mineral oil

1/2 cup glycerin

blue vitriol (copper sulfate, hydrated), about 1 cup

epsom salt (magnesium sulfate, hydrated), about 1 cup

6 medicine droppers, dry

a few wide, squat containers for the blue vitriol and epsom salt

For each child:

1 test tube, 5/8 in. by 4 in. (13 mm wide, 100 mm high), heat resistant

1 test tube holder, metal

1 medicine dropper

2 corks, to fit the test tubes

For each pair of children:

1 jar to serve as a test tube rack e.g., 4-oz baby food jar

1 polyfoam cup, 6- to 8-oz (180- to 240-ml) capacity

1 can of Sterno

1 (or more) piece(s) of aluminum foil, heavy duty, 4 in. by 4 in. (plus asbestos square, optional)

1 piece of paper, small

PREPARATION FOR TEACHING:

Fill the 3-qt polyfoam container half full of cold tap water. The blue vitriol and epsom salt should be placed in the wide-mouthed containers. About 1/4 to 1/2 cup in each container will be adequate and convenient for children to help themselves. Cover the containers with plastic wrap when not in use to prevent the contents from drying out. Set up several stations where the children can obtain their supply when called for in the Activity. Place wooden dispensers (marked as 1 cm) next to each station.

Have the other supplies at a place accessible to the class. Each child can perform the investigation individually. However, pairs of children will share the heat source (Sterno), the supply of water and the jar to hold the test tubes. Because the test tubes will be hot when they are to be stoppered, rubber stoppers must not be substituted for corks.

For Section 3 put out a small supply of mineral oil and of glycerin (1/2 cup of each). These liquids must be placed in dry containers. Cups of bowls are adequate. Next to each of these liquids place several dry medicine droppers for the children to use in obtaining these liquids when called for.

ALLOCATION OF TIME:

The children will need about 1-1/2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Recall with the children what happened when they added heat energy to the blue vitriol crystals.	The crystals lost their blue color.
• In what way did these crystals behave differently from the other solids you investigated?	The salt (sodium chloride) showed no change in appearance. The salol and sugar melted. The sugar also changed in color after it melted. When cooled down, the salol reverted to its original state--it solidified. The blue crystals, however, neither melted nor reverted to their original color when cooled down.
Propose that the children study the effect of adding heat energy to the blue vitriol crystals in greater detail to see if they can find out what causes the color to change.	
Show them a can of Sterno and tell them that, when lit, it is a more intense source of heat energy than the candle	If some children question this, ask how they could check it out. In Grade 3, they investigated the rate at which

TEACHING SEQUENCE	COMMENTARY
flame.	the temperature increased in equal-sized samples of water when subjected to different sources of heat energy.
Open the can of Sterno, light it, and demonstrate to the children how to hold the test tube with the holder so that the tube is not inadvertently released. Also demonstrate how the tube should be slowly moved over the flame with the open end pointing away from any child.	Use an empty tube in this demonstration so as not to detract from the children's discovery of what will happen when they heat the blue crystals.
Each team of two should then get its supply of Sterno, aluminum foil, a jar to serve as a test tube holder, and a half cupful of water from the container. Then each child should get his or her own test tube and medicine dropper. Also, have each one obtain a few extra crystals on a small piece of paper.	They can use these as "controls" for observation.
First, ask each child to put two measures of the blue crystals in one of the two test tubes.	The amount which can be picked up on the 1 cm mark of the wooden dispenser is again considered a "unit measure." If there appears to be any difficulty getting the crystals into the tube, the children can place the required amount on a small piece of paper, cup the paper so it acts as a "slide," and let the crystals slide into the tube. However, popsicle sticks and the like will fit into even these narrow tubes.
After you light their Sterno, each child should heat the blue crystals in the test tube. (Both children's tubes can be heated at the same time.) The heating should be done gently at first, holding the tube above the flame.	Since the Sterno flame is not as visible as the yellow candle flame, the usual precautionary measures in working with flames must be emphasized. For instance, hair must be tied back, the heated object must be removed from the flame before

TEACHING SEQUENCE

After a half-minute or so, when the tube is sure to be all warmed up, it can be held steadily in the upper portion of the flame so that the crystals will be subjected to as much of the heat energy from the flame as possible. Remind the children to observe this system carefully.

- What changes are you aware of?

- Do you notice anything happening in other portions of the system?

COMMENTARY

attempting to observe the contents, arms must not be stretched over any can of Sterno since it might be lit. The cans can be placed on a piece of heavy duty aluminum foil, or asbestos squares if these are used in your school. The flame can be easily extinguished by smothering it with the upside-down Sterno lid placed over the can. (If the lid is not upside down, it might close the can, causing the lid to pop out as the hot contents expand the trapped air.) It is more desirable to extinguish the flame by placing over the top a piece of metal larger than the can, e.g., a piece of aluminum foil.

As you mention the "system" ask some to identify the parts of this system--the test tube and the blue crystals. This particular system is obtaining heat energy from the Sterno. However, since we are not concerned with what is happening within the can of Sterno, we can ignore it in identifying the system.

In a similar manner, we can neglect the test tube holder, if we wish, because it, too, does not enter into the interaction.

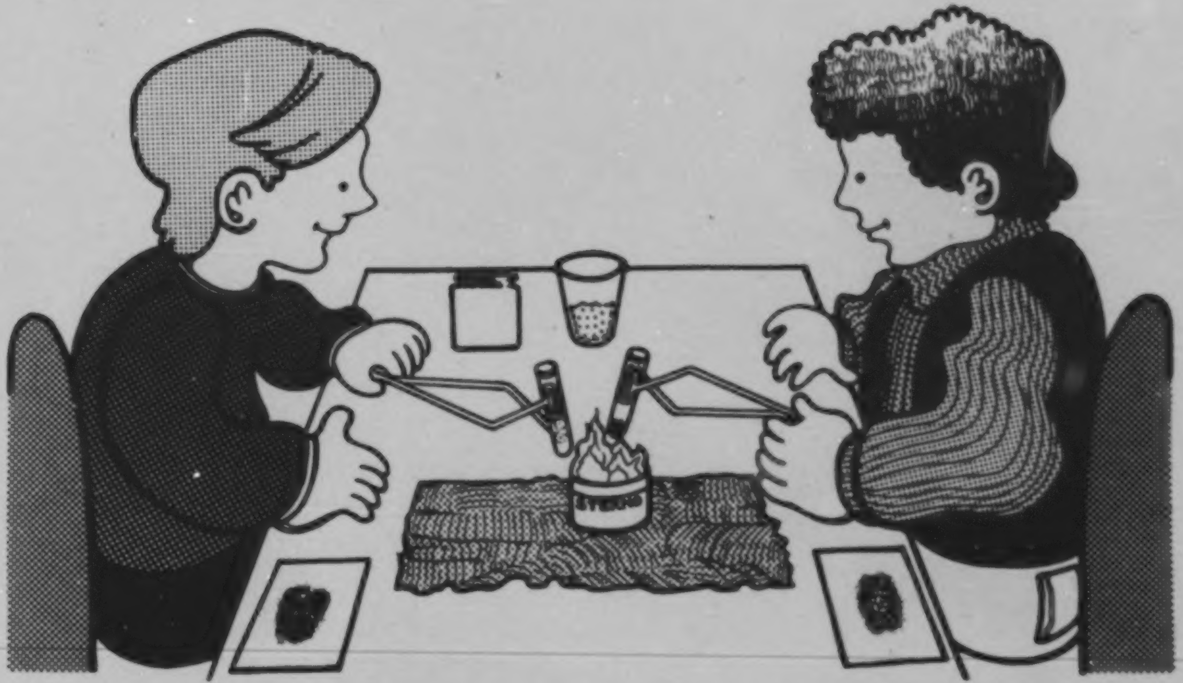
As the children observe the contents of the tube, they may see that the crystals near the glass walls become whitish. As they continue to heat the tube, the remainder of the crystals will lose their deep blue color.

If necessary, direct their attention to the upper part of the tube. Droplets of a colorless liquid will be forming

TEACHING SEQUENCE

COMMENTARY

there. When they heated the blue vitriol in the foil boat, there was no place for droplets to form. But now, since it is confined in the tube, the drops of liquid can condense on the cooler portion of the test tube. Do not identify these drops as water--the children should investigate this for themselves.



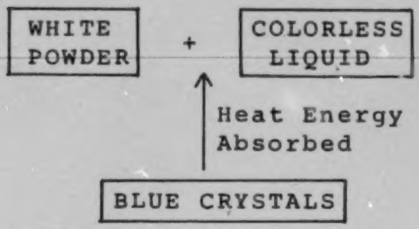
As they continue to heat the contents of the tube, the liquid drops will disappear. If they tend to remain in the tube, have the children heat the upper portions also. They can slowly shift the tube in the flame until all parts have been heated, and until the tube is completely dry.

Once it is dry, they should cautiously place the hot tube

Otherwise, the condensed liquid will run back down the tube when it is cool and turn the white powder blue again, which is undesirable at this point.

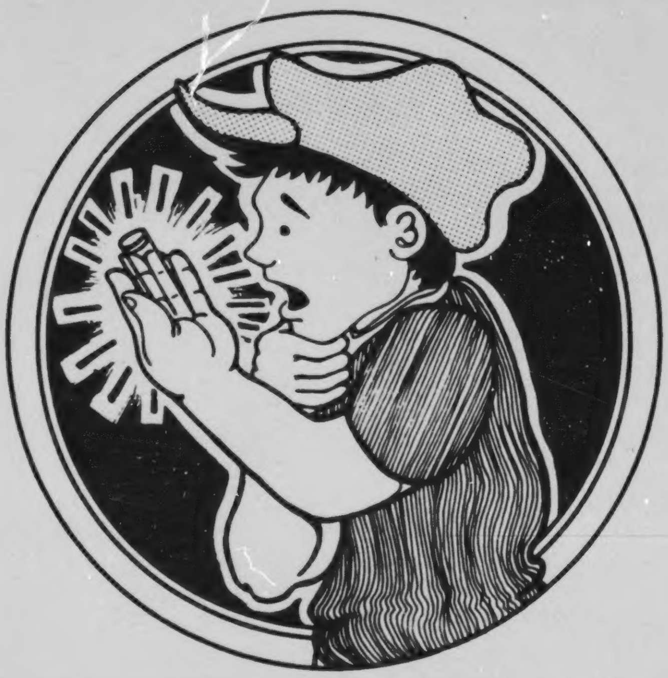
TEACHING SEQUENCE	COMMENTARY
in the jar, handling it only with the test tube holder, then release the holder and gently place the cork on the top of the tube. They should not try to insert the cork. The test tube will be too hot. The Sterno flame can then be extinguished.	The purpose of the cork is to allow the contents to cool down without exposure to the moisture of the air.
As the test tube systems are cooling, open up a discussion about what they have observed.	
• What do the contents of the tubes look like now?	The solid still appears whitish. (Actually this form of copper sulfate is usually described as light green in color).
• Did the blue crystals change in the same way they did when heated in the open boats? Were there any differences?	The color change was the same but, in this case, droplets of a colorless liquid appeared in the upper part of the tube.
• What do you think the liquid is?	Since the drops looked like water, many children will indicate that they think it is water.
• Where do you think the liquid came from?	If any child suggests that the water came from the test tube itself, ask how this hypothesis could be tested. One way is to heat an empty dry test tube over the same type of flame. They may find a tiny bit of moisture but not nearly as much as when they heated the salt crystals.
• Were the blue vitriol crystals wet at the beginning?	No.
• Was any water added to the tube?	No.
• What was added to the system as the liquid appeared?	Only heat energy. Some children may associate not only the color change of the solid, but the formation of liquid with

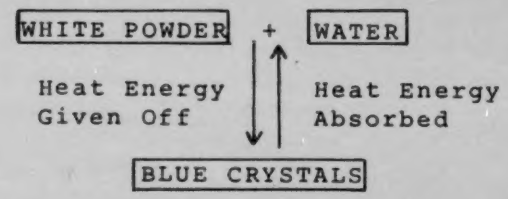
TEACHING SEQUENCE	COMMENTARY
	the addition of heat energy to the system.
Summarize the children's findings up to this point with a schematic diagram:	



TEACHING SEQUENCE	COMMENTARY
2. By now the test tubes should have cooled sufficiently to handle. Have the children place the bottoms of the tubes in the cups of cool water to reduce the temperature still further.	As they do this, be sure the corks remain in place.
• Is the test tube system back to room temperature?	After a few minutes in the cold water bath, it will be.
• What is the color of the crystals now?	Even though the system by now is back at room temperature, the color of the crystals remains almost white. They have not reverted to the color of the control crystals at room temperature.
• How could we get the blue color back again?	If the idea of returning to the system the liquid which they saw forming near the upper portion of the tube is not suggested, you might have to ask about the liquid which left the system.
• What liquid do you want to try adding?	Experience has shown that most children think the colorless liquid was water and want to try adding some of that to the contents of the tube--even though they don't know it was water. However, if they want

TEACHING SEQUENCE	COMMENTARY
	to try out other colorless liquids first, they should be encouraged to do so. (See Section 3 of this Activity.)
• How much water should be put back into the system?	Two or three drops is a good approximation of the amount of liquid driven off, so the children should put no more than two or three drops of water back into the system.
As soon as they have mastered the technique of releasing just 2 or 3 drops of water from the medicine dropper, ask each child to hold the tube in the palm of his or her hand. Then they should remove the cork, and, holding the tube straight up, add the 2 or 3 drops of water directly down so they land on the white material.	Be sure the child can see the contents of the tube. There will be an immediate change in color of the white substance. It will start to turn blue again. Also, within less than half a minute, the children will suddenly feel the release of heat energy. Some systems may even get so hot the children may be quite shocked and even drop their test tubes. This reappearance of both the heat energy and the blue color of the crystals usually generates considerable excitement. Again, see Grade 5, Minisequence III, Activity 4 for an analogous phenomenon.



TEACHING SEQUENCE	COMMENTARY
There will probably be no need to ask the children what is happening. You will hear plenty of evidence that the tube became very hot and that the blue color returned! Once they have calmed down, open up a discussion of their observations:	
• What could account for the reappearance of the blue color and the release of heat energy?	The evidence so far might indicate that water is given off during the transformation of the blue crystals to the white powder. As they add liquid water, and get the original substance back, the heat energy which had been originally added is also returned.
If necessary, review the events with them. During the discussion refer to the schematic on the chalkboard to emphasize that what they are now observing is the reverse of what previously occurred.  WHITE POWDER + WATER Heat Energy Given Off Heat Energy Absorbed BLUE CRYSTALS	
3. At some point, if the question has not come up before, ask the children if water, and water only, is necessary for the white powder to change back to its original state. Challenge them to prove to you that any other colorless liquid, such as glycerin or mineral oil, would not have the same effect. (Show them the glycerin and mineral oil.)	Playing the "devil's advocate" can be a useful technique in inviting children to examine their assumptions. After all, they only observed a colorless liquid form in the cooler portion of the test tube.

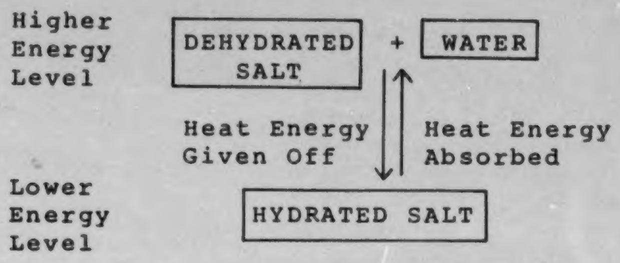
TEACHING SEQUENCE	COMMENTARY
One procedure that they might suggest is to reheat the reformed blue vitriol to again drive off the liquid and then to add either a few drops of mineral oil or glycerin to the tube.	So that all the children can see the effects of adding both substances, you might suggest that one team member work with glycerin and the other with mineral oil.
After all discussion is over, light the Sterno again and let the children add heat energy to the blue crystals once again.	They should again observe the same change from blue to white, and the appearance of drops of liquid in the cooler portions of the tube.
In the same manner as in Section 2, be sure the tube is completely heated so that the condensed liquid is driven off and have them cool the contents. The tube should also be lightly stoppered again.	
After the test tubes have cooled down to room temperature, the children can add to the cooled white powder 2 or 3 drops of the colorless liquids. They should hold the tubes in the same manner as before while they add the drops.	It is very important that the droppers, as well as the supply containers (cups) in which the liquids are made available, be absolutely dry. The presence of any water will give erroneous results.
• What do you observe as the mineral oil is added? As the glycerin is added?	The crystals may exhibit a slight change in color because of being "wetted" by the liquids. However, the intense blue of the original will not reappear nor will there be any evidence of the liberation of heat energy.
• Are these colorless liquids effective in returning the white powder to its original	No.

TEACHING SEQUENCE	COMMENTARY
state?	
Now suggest that the children add 2 or 3 drops of water to the mixture with the "wrong" liquid.	Before doing so, you might suggest that they predict what might happen.
With the addition of the water, the blue color suddenly appears! They again feel some heat energy coming out. In fact, they may observe the liquid hissing as the tube becomes quite hot.	
• What conclusion can you now draw based upon this experiment?	Help the children to realize that the evidence so far is all in favor of the hypothesis that it is water that was driven off the blue vitriol crystals as the temperature was raised.
Finally, using the schematic diagram on page 130, review the interactions they have been observing with particular emphasis on the role of heat energy at each stage and on the concept of reversibility of these interactions.	
• What can you infer was happening as the temperature of the blue crystals was being raised?	Heat energy was added to the system. The color changed from blue to white and water was driven off.
• What does this suggest about the energy level of the white solid as compared with the blue?	Starting in Grade 4, children developed an understanding of the concept of conservation of energy during a variety of interactions. When heat energy is used in a change of state such as melting, the added heat energy becomes part of the increased energy of the mobile liquid molecules. Here, too, the added heat energy becomes part of the products of this interaction--one of which is the white powder. *Thus the white solid must be at a higher*

TEACHING SEQUENCE	COMMENTARY
	energy level then the blue solid.
To help emphasize this concept of the difference in energy levels, ask:	
• What is the evidence that the white solid is at a higher energy level than the blue?	Heat energy is given off by the system when the blue crystals reform.
4. Now suggest that the children investigate another "hydrated" salt under similar conditions to see if it behaves in the same way. Show them the supply of epsom salt.	
Have the children get the same supplies they used when they heated the blue vitriol. They should place a few measures of the substance in the test tube just as they did before.	
Also, suggest that they take some extra salt on a small piece of paper, so they can observe unheated magnesium sulfate and compare it with the heated sample. Before they start heating, ask them to observe and describe the crystals.	Have them use the highest power of magnification on their hand lens.
• What are the similarities between this salt and the blue vitriol?	They both exhibit flat sides and definite angles where the sides meet--all characteristics of a crystal.
• What are the differences?	These are colorless, although the individual crystals are also transparent, as in the blue vitriol. The crystal shape is also different. This difference will be explored further in Minisequence III.
Now have the children use the	

TEACHING SEQUENCE	COMMENTARY
Sterno flame to raise the temperature of the sample in the tube and look for evidence of water being driven off.	Some water will appear in the cooler part of the tube.
Make sure that they drive off all the water from the system and repeat exactly what they did with the dehydration of the blue vitriol.	As before, they should cool the tube in air first and then in cool water.
• Was there any change in color during the heating or cooling process?	No.
Just before they add 2 to 3 drops of water to the supposedly dehydrated salt, ask them to predict what they expect to happen.	If the salt lost water, then heat energy should be released when water is added back.
Then have them do it.	Again they will experience the tube getting hot. It will not be as great as in the case of copper sulfate. Also, if more than the recommended 2 to 3 drops is added, the sensation will not be as great because the extra water will tend to "spread out" (absorb) the released heat energy.
• What indication did you have that magnesium sulfate is a hydrated salt?	Water drops appeared in the upper part of the tube when it was heated.
• Is there necessarily a color change as water is either given off from a hydrated salt or taken on?	Obviously not--the magnesium sulfate was colorless at all stages.
• At which stage was the salt at its highest energy level? How do you know?	After the water was removed. This time both the hydrated and dehydrated forms of the salt are colorless. Thus a change in color cannot be used as evidence that a particular solid is at a higher energy state. However, the children know that the dehydrated salt was at a higher energy level

At this point you might want to generalize the schematic diagram so that it can apply to any hydrated salt. Review what they observed as heat energy is added to and then released from the systems.


Higher Energy Level
DEHYDRATED SALT
+
WATER
Heat Energy Given Off
Heat Energy Absorbed
Lower Energy Level
HYDRATED SALT

If any children have difficulty with this concept, do not push it. They will be given some additional experiences which should help to reinforce these ideas.

because it gave off heat energy when water was returned to it.

The schematic diagram should be left on the chalkboard for reference in Activity 3.

Activity 3 The Hydrate Bond

Throughout COPES, model building accompanies the development of abstract concepts. In this Activity the children will make use of a marble model of a solid to develop the concept of a hydrate bond. At first the children use the marble model to help explain their observations of the effect of adding heat energy to a hydrate like blue vitriol. The dehydrated salt is depicted as being cemented together with strong bonds which cannot be overcome by heat energy from available sources; it cannot be liquefied. The molecules of water are attached with weaker bonds (a plasticene clay) which can more readily be broken off. This model portrays the water as being held in rigid positions at specific sites on the substance, an idea at variance with what one normally finds in the liquid state of water.

Reinforcement of the "dry" nature of the bonded water is provided the children as they observe drops of water absorbed into the powdery solid of a previously "dried" salt. There is no sign of a liquid present as hydrate bonds form. The solid simply assumes the characteristics of the hydrated crystal, accompanied by a release of heat energy. This additional experience reemphasizes that when a bond forms between two entities of matter, energy is given off; the bonded unit is at a lower energy state than either of its components. In the next Activity the children dren will apply these ideas to several situations where bonds are being broken and re-formed.

MATERIALS AND EQUIPMENT:

1 dish, clear, plastic or glass, about 4 inches in diameter

1 marble model of a solid (see Activity 1)

5 marbles of a different color than those above

plasticene clay

plastic wrap

1 polyfoam container, 3 qt (3 liter) capacity

a supply of the following chemicals:

blue vitriol (copper sulfate, hydrated), about 1 cup epsom salt (magnesium sulfate, hydrated), about 1 cup

copper sulfate, anhydrous (see Preparation for Teaching)

epsom salt, anhydrous (see Preparation for Teaching)

sodium carbonate (monohydrate) (optional, obtainable from photographic supply stores)

nickel sulfate, hydrated (optional)

wide containers for the above chemicals

wooden (marked) dispensers

1 microscope (optional)

For each child:

1 magnifier

2 small pieces of paper

1 small wooden stick, e.g., a toothpick

aluminum boats (made from foil) or muffin liner

1 medicine dropper

1 candle (optional)

PREPARATION FOR TEACHING:

Retrieve the marble model of a solid that you made in Activity 1. Set this aside together with the 5 marbles of a different color in a dish, and the plasticene (modeling clay).

As before, half fill the water container with cool water. Put out the chemicals in supply stations with clean, marked dispensers next to each supply. (The anhydrous salts should not be put out until needed, in Section 3.) Be sure each chemical is clearly labeled. Cover the containers with plastic wrap when not in use.

Although the dehydrated salts (also referred to as anhydrous salts) can be purchased from chemical suppliers, you can prepare your own supply from the hydrated crystals you have been using up to now. For each half cupful you will need, place this quantity of the hydrated salt in a pyrex or ceramic dish and heat it in a 350°F (175°C) oven for several hours. After this period, transfer it to a jar which can be tightly covered to prevent rehydration. This procedure works well for both copper sulfate and magnesium sulfate (epsom salt). Just before they are called for, place them in squat containers covered with plastic wrap.

ALLOCATION OF TIME:

The children will need about 1-1/2 hours for this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Have each child obtain a measure of the blue vitriol hydrated crystals and of the epsom salt hydrated crystals on two small pieces of scrap paper. They should also pick up a wooden stick or toothpick.	
Introduce the Activity by asking the children to again observe these crystals carefully.	
Ask them what was given off by these crystals when heat energy interacted with them.	On heating, water was given off.
• Is there any evidence of the presence of water in these crystals?	No.
Using the wooden sticks or toothpicks have them move the crystals about. Do they appear moist or dry?	
Encourage them to view the crystals under magnification. Caution them not to handle the salts.	No water will be visible, of course. If some children wish, they can view a crystal under the microscope. If the microscope is not available, have them use the highest power of their magnifiers. Combinations

TEACHING SEQUENCE	COMMENTARY
	of lenses are possible in the case of certain magnifiers. For instance, with the AS&E magnifier, they can go up to 16X easily, although the depth of focus is then very short.
• Do these substances show the characteristics of a liquid or of a solid?	A solid: they exhibit distinct shapes.
• How can water (or water vapor) come from perfectly dry solids?	Encourage the expression of any ideas the children have to offer. Be sure they back them up with some rational argument.
Help the children to conclude that the water does not appear to be present as a liquid. The task now is to try to develop some idea of what might be the case within the crystal which could explain the observations they have been making.	The task will be to develop a model of a chemical bond. Specifically the children will be developing a concept of the bond between a water molecule and a molecule of a salt. However, the ideas involved can be applied to all chemical bonds. The basic difference between the present bond and that developed in Grade 4 concerning the bond holding a solid together before it melts is that in any solid the units making it up are held in place by bonds exerted in a geometric array around them. In many cases there are bonds in all three directions around a given unit. In the case of the chemical bond, however, the attractive force of the bond is exerted between two units--either two atoms, or two molecules. In the present case it is a bond between a water molecule and the salt molecule in the crystal.
Recall with the children the basic difference in the concept of the structure of	This was developed in Minisequence V of Grade 4 and

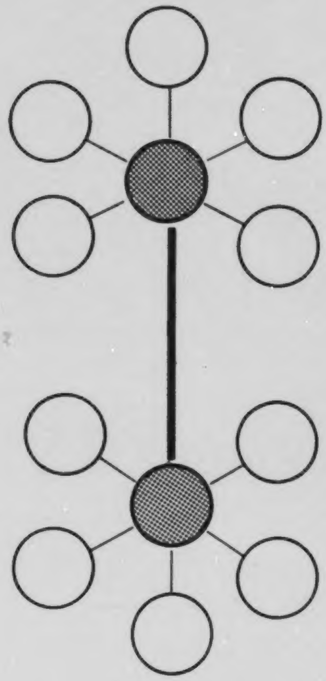
TEACHING SEQUENCE	COMMENTARY
solids as compared with liquids. As you do so, exhibit the marble model you constructed with epoxy in Activity 1. Display this model together with the loose marbles in the dish.	reviewed in Activity 1.
• Which of these models best represents the blue vitriol and the epsom salt?	It would be the cemented one. Its features of rigidity and of straight edges simulate what they have observed in the crystals.
• Which of the substances you have been working with is best represented by the loose marbles?	The liquid water.
• Does water ever show a rigid, solid structure?	One idea that should be offered would be when ice forms from the liquid.
Recall with them now their observations of liquefying solids, such as ice, in Activity 1:	Note that in attempting to build a model, reference is continually made back to the observations. This is to emphasize that the model is meant to help imagine what situation at the submicroscopic, molecular level could account for the observed macroscopic behavior of hydrated salts. The task of model building may be challenging for many children. Most children, however, should ultimately be able to develop a viable model, understand it, and use it to explain other observed phenomena.
• How was the solid structure broken down in some instances?	By adding heat energy to the solid.
• What does the heat energy accomplish? (Refer to the model.)	Presumably, it overcomes the forces binding the molecules within the solid--as in the case of ice, salol, etc.

TEACHING SEQUENCE	COMMENTARY
- Were all binding forces the same strength?	No--the binding forces holding water molecules in ice were the weakest, in salol the next strongest, and sugar the next.
- Did you find some substances which could not be liquefied?	Yes--neither the heat energy from the Sterno nor from the hot plate could liquefy (melt) the sodium chloride. *And*, of course, the white form of copper sulfate could not be liquefied either. Similarly, the anhydrous form of epsom salt also remained a solid when heated over Sterno.
- What, then, can you infer about the binding forces *within* these solids?	See if children are able to infer that the binding forces must be relatively strong because they could not be overcome by the strongest available source of heat energy.
- But what effect *did* the heat energy from the Sterno flame have on the salts?	It apparently drove off water molecules.
Help the children to make the inference now that the water molecules in the hydrated salts must be held in place by bonds which are weaker than those holding the blue vitriol molecules to each other. However, even though the bonds are weaker, they still keep the water rigidly attached in the solid.	
Now, in order to help the children visualize how the water molecules might be attached to the hydrated salts, attach the remaining marbles to the cemented structure with pieces of modeling clay (plasticene). Ask them to imagine that these added marbles represent the water molecules which they have inferred are present in the	Flattened pieces of clay about the size of a pea work well. Note that there is no one correct way of attaching the marbles--the children can have no idea of how the water molecules are oriented with respect to the salt molecules.

TEACHING SEQUENCE	COMMENTARY
salt crystals.	
• Does this model show any signs of mobility in the added water molecules?	The structure as represented by this particular model shows complete rigidity.
In the model not only are the blue vitriol molecules attached to each other by binding forces, but also each water molecule is bonded to the salt molecules. Because of this bond to the salt, the model seems to indicate that the water molecules are not free to move about as they would if they were "alone" in the liquid state.	You might at this point refer to the loose marbles representing the liquid water molecules to reinforce the mobility found in liquids.
• What is the similarity to the structure of ice?	Here also the water molecules are held in position. They are present in a rigid structure.
• What is the difference?	The water in the salt is bonded not to other water molecules, but to salt molecules.
At this point in the discussion, start to draw on the chalkboard a representation of the model.	
	The shaded circles can represent blue vitriol or epsom salt. As you discuss the attachment of the water molecules, insert them as open circles and connect them with lighter lines to the shaded circle. (Circles of the same size can be used. The water molecules are actually smaller than the salt molecules but the children have no way of knowing this.) The lighter lines from the water to the salt indicates a bond which

TEACHING SEQUENCE

COMMENTARY



Discuss the difference in the types of bonds they are presently aware of in the blue vitriol and epsom salt. Note the stronger bond between the salt molecules and weaker ones where the water molecules are attached to the salt. Reinforce this idea by asking a child to pull off one of the marbles representing water from the marble model.

- Can you dislodge the other type of molecules as easily?

Encourage the children to discuss how this model can explain what they have observed on heating hydrated salts. The following points should be

is more easily broken than the bond between the salt molecules themselves.

This will be very easily accomplished. It is stuck on only with clay.

The others will take more of a pull. Of course, with a strong enough pull these marbles can also be removed, but there is a noticeable difference.

TEACHING SEQUENCE	COMMENTARY
covered:	
a) The water is attached to sites on the copper sulfate.	You may introduce the term *chemical bond* at this point to describe the bond directed between the water and the salt. (Actually it may also be referred to as a molecular bond since it is between two molecular species.)
b) The water at these sites is not free to move about as easily as it does when attached to itself. At this temperature, e.g. 25°C, free water is a liquid.	As a liquid its molecules would be free to move about without much restriction.
c) A moderate amount of heat energy added to the substance can overcome the bonds between water and the salt, liberating the water which goes off as a gas (vapor).	
d) When these water molecules in the gaseous state reach the cooler portions of the test tube, they give up some of their extra energy and condense to a liquid.	The children observed droplets of water form at the cooler portions of the tube. This observation illustrates the phenomenon of change of state. If the molecules in a gas (in this case, water) have their extra energy taken away, the bonds exerted between them come into play again and the liquid state is re-formed. (See Activity 5 of Minisequence V in Grade 4.) They drove out the water into the air when they heated the cooler portions of the tube.
e) The heat energy from the Sterno was not	

TEACHING SEQUENCE	COMMENTARY
sufficiently strong to overcome the binding forces holding the blue vitriol or epsom salt to itself in the solid crystal.	As evidenced by the observation that the dehydrated salt did not melt.
3. Keep on the chalkboard the illustration of the reversible processes as heat energy is added to the hydrated salts and when it is given off as water bonds are re-formed. (See page 135.)	This Section of the Activity is concerned with reinforcing some of the ideas of the hydration process; that is, the formation of bonds of water to a salt, accompanied by the release of heat energy.
Show the children your supply of anhydrous blue vitriol. Tell them the water of hydration was already removed.	It may appear very faint blue or green in bulk. Be sure the container is covered with a cap or plastic wrap to prevent moisture from reentering.
Ask them where this salt belongs on the energy chart on the board.	Have them identify that it would be represented by the salt at the top.
• What would you predict would happen if you added a little water to a sample?	For one thing, it should turn blue; for another, heat energy would be given off.
• Would you expect the solid to appear wet with water?	Those children who have understood that added water will re-form hydrate bonds will respond that it will look like the original blue crystals. Don't be concerned if some children may still be unsure. Shortly they will perform the experiment themselves.
• Which do you think has more energy in it--this anhydrous salt or the blue crystals?	
Have the children obtain (or make another) aluminum foil boat. They should also obtain a wooden dispenser and go to the chemical supply station for 2 or 3 measures of the anhydrous salt. Have them observe it and describe the	Under magnification, it appears as a very fine, almost white

TEACHING SEQUENCE	COMMENTARY
appearance.	powder.
Now, have them hold the boat in the palm of one hand while they add 1 or 2 drops of water to the white salt.	There will be an immediate change in color to a distinct blue. Also, the bottom of the boat will begin to feel very warm.
• What do you think is happening?	Bonds are forming. As they respond, direct their attention to the downward reaction on the schematic on the chalkboard.
• Where is the extra energy of the white salt now?	Given off as heat energy.
• Where is the water?	Again refer to the schematic, emphasizing the bond formation between water and the anhydrous salt.
As they observe the salt in the boat, have them shake it about. Does it appear wet? They can use the sticks to get a "feel" for the condition of the salt.	The water will appear to be absorbed completely by the solid powder. As they "feel" the crystals with the stick, they will appear dry.
Use the schematic on the board to reemphasize what has happened to the anhydrous salt and the water.	The important idea they should be getting is an understanding that as the water bonds *form*, heat energy is *given off*--that the salt with the bonds is at a *lower* energy state. The extra energy contained in anhydrous material is given off as the bonds with water re-form, resulting in a dry solid. For those children interested in repeating this type of observation, have them obtain a few measures of magnesium sulfate which has also been dehydrated (see Preparation for Teaching) and repeat the procedure. Again the water will appear to be "taken up" by the anhydrous salt. No color change, of course, will accompany this.

EXTENDED EXPERIENCES:

1. If other anhydrous salts are available, the children can perform additional experiments. For instance, sodium carbonate (monohydrate), which is available in photographic supply stores, will take on water and form a more highly hydrated salt. Again, the added water will appear to be absorbed. Both forms of the carbonate are colorless, as was true of epsom salt.

2. Other hydrated salts can be investigated in a fashion similar to the blue vitriol. In the next Activity they will have an opportunity to investigate two more, cobalt chloride and sodium acetate or sodium thiosulfate. If fine crystals of hydrated nickel sulfate (deep green) are available, children can place a few measures in a test tube and dehydrate it. (If the children use the aluminum boats for the heating, use the candle flame and not the Sterno. The thinness of the foil might result in melting the aluminum over the hotter sterno flame.) The anhydrous form is yellow. However, this salt is not as "cooperative." It takes a long while for the hydrate bonds to re-form when water is added.

3. What happens to some of these hydrates if left open to the air? Children should be aware that there is heat energy available from the room. After all, an ice cube can melt at room temperature, a process which requires heat energy. Will some of these hydrates also have water bonds broken by the heat energy of the room? How can they find out?

Activity 4 Using the Model

In this Activity the children experiment with a variety of additional hydrated salts, both colored and colorless, as they expand their experiences with the role of heat energy in the breaking and formation of bonds. They discover that when a solid salt interacts with water, heat energy may either be given off or absorbed, depending upon whether the salt was hydrated or dehydrated to start with. In forming solutions with water, if bonds to water have to be formed first, the system will get hot--heat energy will be given off. If water bonds are already present, the interaction with water as the salt goes into solution is accompanied by an absorption of heat energy which is used to free the salt molecules from the binding forces holding them in the solid. In that case, the system cools during solution-making. Thus, the children establish a criterion for determining if bonds to water have to be formed along with the dissolving of the salt. Is the solution process accompanied by an increase or decrease in temperature? If accompanied by an increase, bonds are being formed with water; if a decrease, the bonds holding the solid are being broken. These ideas are established as the children work with cobalt chloride, sodium acetate and sodium thiosulfate, the last two being colorless salts.

MATERIALS AND EQUIPMENT:

For the class:

safety matches

1 polyfoam water container, 3 qt (3 liter) capacity

plastic wrap

1 test tube, any size

paper towels

several wide-mouthed containers plus wooden splints as dispensers of chemicals

Supply of the following salts: (1/2 to 1 cup)

cobalt(ous) chloride, hydrated, fine crystals

"hypo" (sodium thiosulfate), hydrated crystals sodium acetate, hydrated crystals

For each child:

2 test tubes, 100 mm x 13 mm

1 test-tube holder, metal

1 beaker, heat resistant, 30 ml capacity

1 thermometer, -20°C to 50°C, e.g., Macalaster No. 2662 (optional)

1 medicine dropper

1 magnifier

For each team of two:'

1 jar to serve as test tube rack

1 can Sterno with aluminum foil to set it on

1 cup, plastic or polyfoam for water supply

extra pieces of paper and of aluminum foil

PREPARATION FOR TEACHING:

Half-fill the polyfoam container with room temperature water (20-25°C). Have the hydrated crystals of cobalt chloride, sodium thiosulfate and sodium acetate available in wide-mouthed containers together with wooden dispensers marked at the 1-cm level. The containers should be covered with plastic wrap when not in use to prevent premature loss of water. (This will also prevent the cobalt chloride from picking up moisture if the air in the room is humid.) If the cobalt chloride is not in the form of very fine crystals, break it up by putting the larger crystals in a cloth bag and banging it with a hammer. Place the different chemicals in different locations to avoid contamination.

Have the other materials the children will need accessible to them. This should include the test tubes, beakers, test tube holders, Sterno, aluminum foil, jars, cups, magnifiers, water supply and optional thermometers.

ALLOCATION OF TIME:

The children will need about 2 or 3 hours for this Activity.

TEACHING SEQUENCE

1. Place a small sample of the hydrated cobalt chloride in a test tube and show it to the class.

Tell them this is a salt called cobalt chloride. The question is: Is it hydrated? Does it have water molecules bonded to it?

Now have them proceed with the experiment.

Have each team obtain their water supply in the polyfoam cup, a can of Sterno plus its required foil, 2 beakers, a test tube holder and medicine dropper.

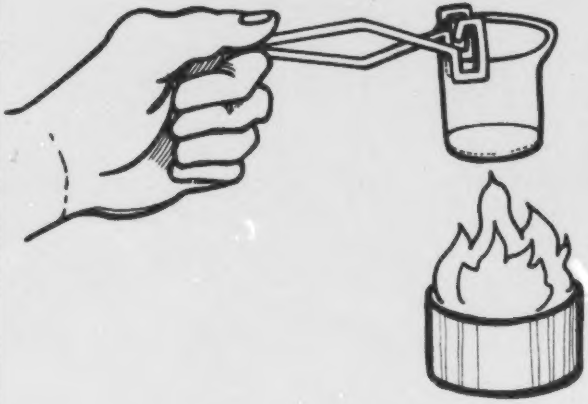
Tell the children that they will be heating some of the salt in the beaker. Show them how the beaker is to be held with the test tube holder as it is heated over the Sterno flame. Grabbing it on a side (as illustrated) will ensure a firm grip. Once they have mastered the technique of holding the beaker, have the teams place two measures of cobalt chloride in each of the two beakers.

COMMENTARY

The children should be ready with suggestions on how to find out: get any possible bound water off by heating and then, if water is returned to the system, the original material plus heat energy should be produced.

In this Section the children will be working in teams of two. If they are to work individually, alter the materials requirement accordingly.

They will be placing a small layer of the cobalt chloride on the bottom of the beakers to be heated. They must not use aluminum boats for this since the cobalt chloride will interact with the aluminum and destroy it.



TEACHING SEQUENCE

Once they obtain the salt, have them observe the crystals closely with either the magnifier or microscope.

Using the same precautionary procedures outlined before, ask them to set up the heating source and then light it for them.

Have them heat *one* sample carefully and look for any changes--for signs of an interaction. They should hold the beaker over the flame until the contents appear dry.

After extinguishing the flame, set the beaker on a piece of foil to cool back to room temperature. It would be advisable to put a covering on while it is cooling but *do not use plastic wrap*. The beaker will be too hot. Instead, place a small piece of metal foil on the top of the hot beaker.

While the beaker is cooling off, discuss what they have just observed.

- Did you see any evidence of water cooling off?

COMMENTARY

The amount of salt they take should form a thin layer on the bottom of the beaker.

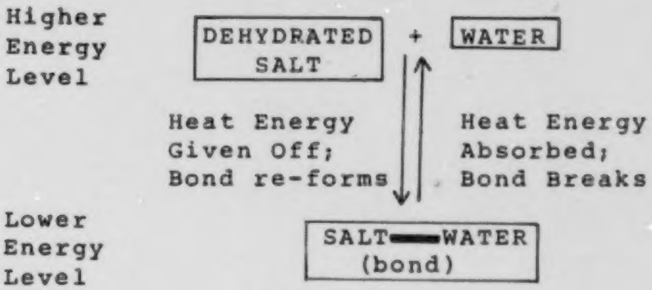
On close inspection these red crystals will be transparent. If there happens to be some perfectly formed ones, they will appear as cubes.

As the cobalt chloride is heated, it starts to lose bonded water and its color changes to blue. In fact, so much water is driven off that before it all leaves, some of the salt may tend to form a solution with the liberated water. However, if only a thin layer of salt has been heated, the dehydration process will not be confused by this phenomenon.

Some children may have seen some evidence of water initially as the blue substance was created; there may have appeared to be some liquid

TEACHING SEQUENCE	COMMENTARY
	present. But unless they had placed a loose cover over the top of the beaker where water could have condensed, they would not have been aware of it leaving the system.
• How can you tell for sure if the blue material is a dehydrated form of cobalt chloride?	By adding back a drop or two of water and seeing if the red reforms.
• What else would you expect to observe if the blue form were really a dehydrated form of the salt?	Heat energy should be released as the water bonds are reformed, as well as the return of the original color.
When the beaker is no longer hot to the touch, the bottom can be immersed in the cup of water to hasten cooling. Dry off the beaker.	
Now, as one child holds the beaker in the palm of his or her hand, have the other child add 2 or 3 drops of water.	This time just enough water should be added so that the hydrate not only re-forms but a very small amount of (red) solution is formed as well. Be careful here because if too much water is added, the liberated heat energy will be dissipated over too great an amount of material and the children may not be able to feel the warmth.
• What happens?	There is a return to the original color and the beaker feels warm. (If on standing some of the dehydrated salt molecules rebond some water from the air, the solid will start to appear purple, the combination of blue and red.)
• Did the red material lose bonded water when heat energy was added?	Since the color not only returned, but it did so with the evolution of heat energy, the evidence is all in favor of the red cobalt chloride having water bonded to it. It is

TEACHING SEQUENCE	COMMENTARY
In discussing this return to the original state, amplify the generalized chalkboard diagram to emphasize the reversible nature of this process. This time show a schematic bond between the salt and water at the lower energy level.	hydrated. The blue is the dehydrated, or anhydrous, form of the salt.


Higher Energy Level
DEHYDRATED SALT
+
WATER
Heat Energy Given Off; Bond re-forms
Heat Energy Absorbed; Bond Breaks
Lower Energy Level
SALT—WATER
(bond)

TEACHING SEQUENCE	COMMENTARY
	Whenever you consider it appropriate, discuss with the children the concept of the accountability of heat energy in these reversible changes: that heat energy must be taken in to break the bond, that the energy is then present within the products formed, and that when the water and the salt form bonds again, the heat energy reappears. It is hoped that eventually the children may be able to transfer this concept to the making and breaking of any bond in a molecule.
2. Refer now to the small bit of red solution which formed in the beakers.	
• When this solution formed, was heat energy absorbed or given off?	Since the system became warm, heat energy was being given off as the water rebonded to the salt.
• Is this normally the case	Not always--in Grade 5 of the

TEACHING SEQUENCE

when solutions form? Discuss any examples the children may recall.

If necessary, to reinforce this idea of the absorption of heat energy as solutions are made, let them take 1/2 teaspoon of table salt (sodium chloride), place it in a small cup or beaker, insert a thermometer, and then add a dropperful of water of known temperature and observe what happens. The temperature of the salt-water system will drop a few degrees--an indication that heat energy is being "taken up" as the salt dissolves.

- Suppose you made up a solution of the cobalt chloride crystals that had not been dehydrated--the red ones. Would you still expect the system to warm up as water is added?

Suggest that they try doing

COMMENTARY

COPES curriculum, children worked with a variety of salts dissolving in water. In all the cases they investigated, heat energy was absorbed as the salts dissolved. The systems cooled down. Based on these observations and their prior experiences with change of state, they inferred that it took energy and the attractive force between water and the solid salt to break the bonds holding the molecules together in the solid. If the children have not had these experiences, you may want to interpose a telescoped version of Activity 2 of Minisequence III of Grade 5 at this point; if they have had them, you may still find the brief review described under the teaching sequence helpful.

If they are using the plastic-backed thermometers, cut off the plastic about 1/2 inch up from the bottom to expose the bulb so it rests on the bottom of the container and is surrounded by the small quantity of solution. To measure out a dropperful of water, the children should insert the dropper, squeeze the bulb, and let as much liquid come up into the tube while still immersed as can. This is about 1/4 teaspoon of liquid if you use standard droppers.

Encourage their speculations and reasons for them.

TEACHING SEQUENCE	COMMENTARY
it: First rinse out and dry their beakers and then put 1 teaspoon of red unheated cobalt chloride into it. The teams should then check the temperature of their water supplies, insert the thermometer in the sample of crystals, and add a dropperful of the water to them.	
• What happens to the temperature of this system?	It drops about 2 or 3 degrees. (The reason for working with a larger sample of the salt is to get a measureable change in temperature.)
• How does this compare with the temperature change when water was added to dried-out cobalt chloride?	Then the temperature rose.
• What was the color of the solution in each case?	The color was the same in both cases, although the red color may have been more intense where the spoonful of crystals was dissolved because of the larger amount of cobalt chloride.
Help the children to understand that in both cases they obtained a solution of cobalt chloride in water.	
• Why did the temperature go up in one and down in the other?	Encourage them to discuss this question thoroughly. The difference is due to the fact that in the case of the dehydrated salt, as water is added, bonds are formed between water and salt and heat energy is given off; in the second case, the red crystals already have water bonded to them--thus, when they interact with more water to form a solution, heat energy is absorbed in breaking apart the crystal structure.
If the children have	

TEACHING SEQUENCE	COMMENTARY
difficulty with this question, use the schematic diagram of heat energy and bond formation they have been developing to help them provide an explanation for these differences.	
Ask such leading questions as:	
• What is the difference in the two substances to which the water was added?	In one, there was no water bonded to the salt. It would correspond to the higher energy state salt. In the other (the unheated salt), the water bonds are already present.
• What occurs as water is added to the blue salt which had been heated?	Refer to the salt at the top of the schematic diagram. Water bonds will form.
• As water bonds form, is heat energy given off or absorbed?	It is given off as the process proceeds down in the schematic to the hydrated salt.
• What do you think is happening as water interacts with the unheated red crystals?	The red crystals are dissolving: The bonds holding the cobalt chloride in the patterned structure of the solid are being overcome to free the salt to become part of the liquid solution. (See Minisequence III, Grade 5.)
• Is heat energy absorbed or given off as these crystal bonds are overcome?	Heat energy is absorbed (taken in). It is used to "liquefy" the red crystals as they dissolve in the water.
• What is the evidence that heat energy is being absorbed?	The very fact that the temperature decreased--that the system became cooler--meant that heat energy was being absorbed from the surroundings, which included the water.
3. Will the phenomenon they have just observed be true of any hydrate? That is, when water is added to a soluble hydrated salt, does the temperature decrease, signifying	In this Section of the Activity, the children will again find that, when water is added to hydrated salts, whether the system becomes warmer or cooler depends on whether bonds to

TEACHING SEQUENCE

the absorption of heat energy? When water is added to the dehydrated salt, does the temperature increase, signifying the liberation of heat energy as hydrate bonds are formed?

To find out, each child will now need 2 test tubes, a test tube holder and a medicine dropper. The team will share a can of Sterno, a jar in which to place the tubes, and a cup half filled with water at room temperature. They can share the observations if one child works with sodium acetate and the other with sodium thiosulfate. Each child should place 2 or 3 measures of the salt he or she will be investigating into each of their two test tubes.

Have them observe each of the salts and note its properties.

Then each child should place one of the test tubes in the rack substitute and heat the other test tube after the Sterno is lit. While it is being heated, the system should be observed carefully.

At first the contents will give the appearance of melting.

COMMENTARY

water have to be formed before solution-making takes place. It is suggested that teams of two share the experience with the two hydrates, sodium acetate and sodium thiosulfate.

These are the same salts which were investigated in Grade 5, Minisequence III, Heat Energy and Liquefying Solids. The properties they may note are the color, (both are white, or if they happened to look at a few crystals under the microscope, they will appear clear and colorless) and distinct crystal shapes.

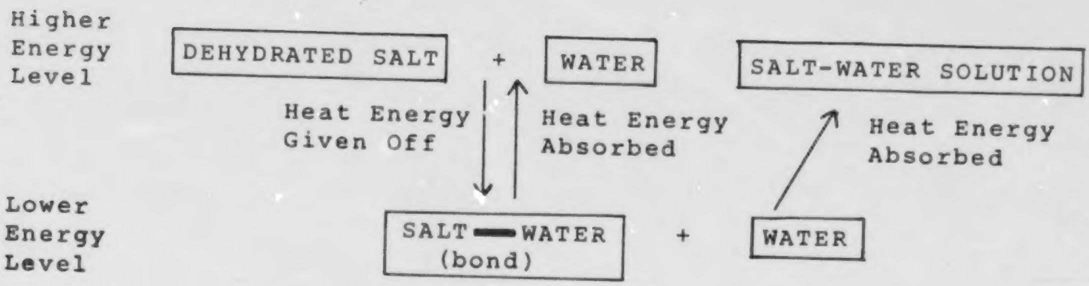
Be sure the usual precautions with Sterno are observed, particularly the one about not letting the mouth of the test tube be directed at any other child.

Actually what is happening is that so many hydrate bonds are being broken--so much water is being liberated--that initially the very soluble salts are dissolving in this freed water. In this respect these salts

TEACHING SEQUENCE	COMMENTARY
	are like cobalt chloride.
As heat energy continues to be added, the freed water will cause bubbling. When the children observe these changes, ask them what interactions they believe are taking place.	Some may respond that a change in state--melting--is taking place. If they do, ask them to reserve judgment until they complete the heating. Other children may refer to the boiling as another change in state, water becoming a gas. Still others, because of all their previous experiences, may assume that some hydrate bonds are being broken as heat energy is supplied to the system.
Ask them to continue the heating until no more changes are apparent.	In both the sodium acetate and thiosulfate, the contents will "dry up" and a white powdery solid will remain.
• What do you think is the difference between the contents of the tube you heated and those of the unheated "control?"	Some may respond that bonded water was driven off from the heated tube. (Its contents also look more powdery and less crystal-like.)
• If water bonds were being broken by the addition of heat energy, what would you expect when you add a few drops of water after cooling the system down to room temperature? Why?	Based on their prior experiences, they sould expect that the system would become hot. If water bonds had been broken by the heating, then as they re-form, heat energy must be given off. Thus the temperature will rise.
Now have them test their predictions. They should add a drop or two of water, holding the tube in the same manner they did in the previous Activity.	
• What happens?	The system gets very hot.
• Could you also use the	No, because both the hydrated

TEACHING SEQUENCE	COMMENTARY
return of color as a criterion for sensing the reversal of the water loss, as with both cobalt chloride and copper sulfate?	and anhydrous forms of sodium acetate and of sodium thiosulfate are colorless--as in the case of epsom salts.
• Therefore, what is the only evidence to confirm that the original substance was re-formed?	The liberation of heat energy as the original bonds re-formed.
For those children who may have suggested that some of the salt "melted" when heat energy was initially added, ask what they think now.	Help them to recall that melting means that the bonds holding the solid together are broken as the solid becomes liquid. Dissolving, or interaction with water, can also produce a liquid. But they saw in Grade 5 that this involves adding a second component, water.
• Was the heat energy (available from the Sterno) sufficient to break down the bonds holding the solid in its structure?	Apparently not. After all the water was driven off, no liquid remained. It was all solid. The liquid formed at first was probably produced as the salt dissolved in the water being released from the hydrate. Once the water left the system as a gas, no more liquid solution could form.
Now focus attention on the unheated "control" system.	
• What do you predict will happen if a few drops of water are added to this test tube?	Those children who developed a full understanding of the experiment as they added water to the dehydrated and hydrated cobalt chloride will respond that the system will become cooler. Don't be surprised, however, if you get a variety of responses.
Have each child hold the test tube containing the unheated (hydrated) salt in the palm of their hand as they did with the heated one. Add a few	

TEACHING SEQUENCE	COMMENTARY
drops of water to the system.	
• What do you observe?	Dissolving will take place. The test tube and its contents will start to feel very cool. Some children may still be surprised at this difference.
• Why do you think this unheated sample is behaving so differently?	Encourage the children to use the schematics on the board to justify any of their ideas.
As soon as the children have had time enough to discuss their ideas on the differences in the responses of each system, the concluding discussion should develop the following understandings:	
a) The few drops of water which were added to the heated dehydrated salt formed bonds to the salt. As these bonds were forming, heat energy was given off. (Since heat energy was absorbed to break the bond, when the reverse was taking place, heat energy was given off.)	
b) In the unheated sample, the salt had its water already attached. All that the water was doing was interacting with the salt to form a solution. As you discuss this point, refer to the molecular model diagram which shows the attachments to water. In one instance these are all intact; in the other (the heated sample), the bonds have been severed.	
Conclude the discussion by completing the schematic of the reactions:	



EXTENDED EXPERIENCES:

1. Often children enjoy the challenge of trying to find out "which is (are) the hydrated salt(s)." A simple form of this game can be played with the hydrated and dehydrated forms of only one substance--for instance, epsom salt (magnesium sulfate). Set up several stations around the room, some of which contain salt which has been previously dried by heating it in a 350°F (175°C) oven for a few hours as described in the Preparation for Teaching of Activity 3. If necessary, pulverize the hydrated epsom salt crystals in order to assure that the two forms of the substance can not be told apart on the basis of their physical appearance. Following the same procedures outlined in this Activity, the children will find that the dehydrated salt increases in temperature when a few drops of water are added to it, whereas the hydrated one decreases in temperature. [Cautionary note: The drugstore variety of epsom salt may be partially dried out. If so, it will give misleading results when water is added. (The system will heat up.) Thus you should pretest the "hydrated" crystals to be sure the system cools down when water is added. If the epsom salt is obtained from a chemical supply house, you should not encounter this problem.] A more elaborate game would involve other substances, such as calcium chloride, washing soda (one form of sodium carbonate), and sodium carbonate (monohydrated). The latter two substances will both get warm on adding water, but one more than the other. Why? Washing soda loses only a few attached waters, the other many more. Caution the children not to get sodium carbonate on their hands.

2. The following is a nice tie-in with Minisequence I: Cobalt chloride can be used as an indicator of moisture conditions in the air. Remember that the red form is hydrated; the blue, dehydrated. Place some red crystals on a flat dish and observe them over a period of time. On standing in the room, if the humidity is low, they may start to lose some bonded water. The color will at first become purple, then blue, as it loses water. Where does the heat energy come from?--the objects and containers in the room. The crystals may change in physical

appearance, too: on "dry" days of low relative humidity, they tend to crumble and form very small bluish ones (the dehydrated form). When it rains, or on very humid days, the color may change back again and become pink (it appears pink, not red, due to the powdery nature of the crystals once they have been dehydrated). Don't attempt this in a completely dehumidified, air-conditioned room.

Activity 5 Extending the Model

The concept of the heat of bond formation is applied to a different type of bond in this final Activity--the starch-iodine bond. However, the same reasoning applies to this deep blue interaction product of starch and iodine. Children discover that the blue color disappears if heat energy is added to the system. Assuming this might have resulted from the breaking of a bond between the two molecular units, starch and iodine, the children predict that if heat energy were taken away, the bond could re-form. Re-formation of the bond, they predict, should be evidenced by reappearance of the deep blue color. Experimental verification of this prediction reinforces the usefulness of the bond model they have been introduced to--it "works" for other bonds, not just hydrate bonds. In addition, the absorption and release of heat energy continues to reinforce the accountability of heat energy, which does not seem to disappear, but returns as these reversible systems return to their original condition. Although none of these ideas can be put to the test of quantitative verification as was the water-mix in Grade 4, it is hoped that by this time a faith in the concept of conservation of heat energy as related to energy conversions on the molecular level will become a part of the child's approach to events in nature.

MATERIALS AND EQUIPMENT:

1	saucepan, 1-qt (1-liter)
1	box cornstarch
1	oz tincture of iodine
1	pint jar
3	paper towels or 1 disk (30-cm) of filter paper
1	funnel, approximately 6-in. (15-cm) in diameter
1	ring stand assembly or cardboard box, approximately 12-in. by 12-in. (30-cm by 30-cm), with a hole cut in one side through which a funnel can be supported
1	laboratory thermometer, -20°C to +110°C
1	jar with screw lid, 1-qt (1-liter) capacity

1 stirring spoon

For each child:

1 cup, 1-oz (approximately 30-ml), plastic or waxed paper

1 thermometer, -20°C to 50°C (optional)

1 jar or a test tube rack

1 test tube, 100 mm x 13 mm

1 test-tube holder, metal

1 cup for water supply

1 medicine dropper

For each team:

1 can Sterno, with aluminum foil to set it on

PREPARATION FOR TEACHING:

You will have to prepare a starch solution ahead of time. No more than a day before class, prepare 1 quart of a starch-water solution by heating 1/2 teaspoon of starch in a cup of water. Heat it to about 80°C for 5 to 10 minutes and filter. The filtering will take about 15 minutes because the filter gradually becomes clogged with starch, but most of the liquid comes through in the first few minutes. The filtrate, containing the dissolved starch, can be diluted with enough water to make a quart of solution. Test a small sample of it for a positive starch test with iodine. Discard the test sample. Store the clear starch solution in a quart jar, preferably in a refrigerator or other cool place.

The iodine solution should be prepared by adding 10 or 12 drops of tincture of iodine to a pint of water. The resulting solution will be a light yellow-brown. Each child will need about 1/2 teaspoon of this solution. If the solution stands around for several days, the iodine will evaporate from it even if the container is covered. All you need do in that case is add additional drops of the tincture until the original color is obtained.

ALLOCATION OF TIME:

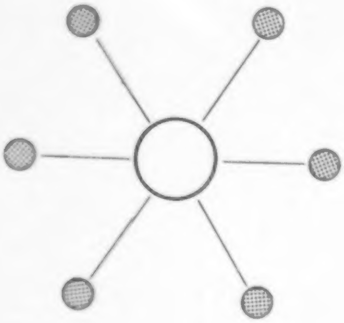
The children will need only about 1 hour to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Show the children the starch solution. Ask if they can recall any properties of such solutions.	In Grades 3 and 4 of COPES, the children had a variety of experiences with starch and its solutions. Its interaction with an iodine solution was used as a test for the presence of starch.
If no child recalls the special interaction property with iodine, place some of the solution in a test tube and add a few drops of the iodine solution. It would also be advisable to let them test some familiar substances with the iodine: oatmeal, cornstarch, banana, etc. Even paper toweling will give the blue-black interaction product of starch and iodine.	The contents of the tube will turn a deep blue.
Now have each child obtain a clean test tube, test-tube holder, medicine dropper, and a jar.	A Sterno can will again be shared with teammates.
Set out the solutions of starch and iodine so that the children can help themselves.	The solutions can be placed at central stations or you can place small amounts of the solutions in 1-oz cups (1/2 full) at work areas which 4 or more children can share.
Have them place about two droppersful of the dilute iodine solution into the test tube.	One medicine dropper should be used by the pair of children to get the iodine. Then the other can be used to obtain the starch solution (see below).
• What will happen when the starch solution is added?	They should expect the liquid to turn blue.
Each child should take up a small amount of the starch solution in the other clean dropper. Then they should add about 2 drops of the	

TEACHING SEQUENCE

starch solution to the test tube and gently swirl the contents.

If the suggestion does not come from the class, present the hypothesis yourself that possibly the starch and iodine are held together by a bond similar to the bond between the solid salts and water molecules they have been investigating. To assist in discussing this hypothesis and its implications, use a diagram on the board. Draw a circle to represent the starch molecule and other (smaller) circles to represent the iodine molecule(s).



COMMENTARY

An intense deep blue color will form immediately. (The color of the solution may vary slightly depending on how much starch is present. This is not important.) If the deep blue color seems "reluctant" either to form or to persist, have them add a few more drops of the starch solution.

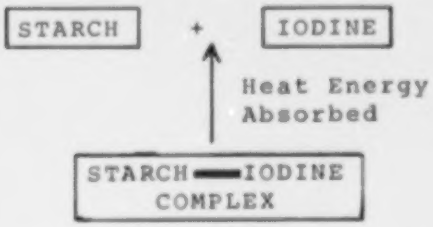
Many people call this blue substance the *starch-iodine complex*. If you wish, use this name for it.

In Grade 4, the children discovered, by molecular sieving, that the iodine molecule, in solution, is smaller than the starch molecule.

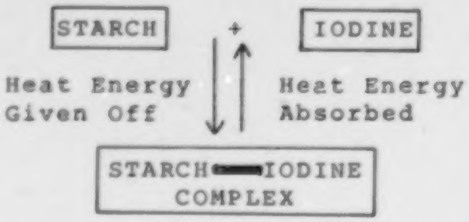
TEACHING SEQUENCE	COMMENTARY
As in the case of the hydrates, draw lines representing the bonds between the two kinds of molecules.	
• Assuming the deep blue "complex" is the result of a bond between starch and iodine molecules, what can you predict would happen to it if heat energy were added?	Based on all their prior experience with hydrate bonds, they should expect that the bond would be broken.
Ask them to change the diagram to fit this prediction.	The diagram now sbould indicate that upon the addition of heat energy the bonds are broken and starch and iodine molecules are separated.
• Would the color of this product also be expect to be blue?	Not really. When they had the separate solutions, the starch was colorless and the iodine alone was very faint yellow. The blue formed only when they interacted.
Now light the Sterno and ask the children to heat the contents of the tube gently.	Again be very careful that they direct the mouth of the tube away from anyone.
• What happens within this system?	The color will start to fade and eventually will be completely "bleached out."
As soon as the color change occurs, have them place the tubes gently in the jar which serves as a test tube rack. While the system is cooling down, ask them for their ideas about what the added heat energy was doing.	Some children may say that the iodine just boiled away. This is certainly a reasonable idea since the color produced when it was present has disappeared. Some enterprising youngster may eventually want to test this out by heating some iodine solution alone in a test tube. The iodine solution will be faintly yellow and if heated

TEACHING SEQUENCE	COMMENTARY
	for the same time as they did with the starch, will not show much, if any, evidence of change in color. (Eventually, on prolonged heating, or standing, the iodine will leave the system and go off as a gas and the yellow color will disappear.)

At this point, you might put a schematic diagram on the board which would represent the hypothesized interactions:



TEACHING SEQUENCE	COMMENTARY
• With this schematic as a focus for discussion, can you predict how the blue color of the complex might be re-formed?	Based on their experience with hydrate bonds, and since the diagram illustrates that it was the addition of heat energy which broke the bond, help the children to see that taking heat energy away might allow the bond to re-form.
• How can you test this out?	Remove heat energy by cooling the system and look for the return of the blue color which indicates the bonded complex.
Have the children look at the test tubes which have been standing during the discussion.	Most tubes will still be warm and the contents will still be colorless.
• How can you remove still more heat energy?	Some will suggest a cold water bath, ice, or even putting it in the refrigerator. All these suggestions are fine.
Suggest that they cool the test tube still further in some cold water.	They can get a supply from the cold water tap or a reservoir of cold water you have set up

TEACHING SEQUENCE	COMMENTARY
	for them.
As the tube is immersed in the cold water it should be swirled about a bit.	Very soon, the deep blue color will start to return--near the walls at first. This may be quite a surprising confirmation of the hypothetical model. The diagram can now be completed as follows:  STARCH + IODINE Heat Energy Given Off Heat Energy Absorbed STARCH—IODINE COMPLEX
Many children will want to see if these changes can be repeated.	It can be reversed so long as the iodine doesn't evaporate. If it does, add some fresh iodine and the intense color of the complex will return.
The concluding discussion should return to the concepts introduced with hydrate bonds: a) It takes energy to break a bond. b) A bond can re-form if energy can be removed and if the components are present to form that bond.	
• How does this interaction differ from your experience with hydrates?	In the hydrates, the water which was part of the bond left the system. To reverse the interaction, water had to be added. Here, all the substances are still in the system; all they have to do is to take away heat energy.
• What inferences can you now make about the heat energy absorbed by a bond as it	

TEACHING SEQUENCE	COMMENTARY
breaks? Is the heat energy lost somewhere?	Not really--it should be present in the higher energy of the substances formed.
If necessary, help the children conclude that this absorbed energy is part of the more "energetic" dehydrated salt molecules and the starch and iodine molecules.	
• Which solids had the more energetic molecules in the examples you investigated?	The "white vitriol" and the blue form of cobalt chloride, for instance. In the case of the colorless salts, it could only be identified as the solid left after heating. When separated, the starch was colorless and the iodine was yellow.
• Were you able to get the heat energy back?	Yes. All these examples were reversible. In the case of the dehydrated salts, the original conditions were obtained again if the water was put back. Then the heat energy reappeared as the bond reformed. In the case of the starch-iodine, they could not easily measure the liberation of heat energy as the bond reformed, but the release of heat energy was assisted by cooling the system. In an extension described below, some children may actually be able to measure the liberation of heat as the starch-iodine bond is formed. In any event, these Activities should have provided the children with the idea that heat energy can cause changes and that after it is so used, it can be recovered. Heat energy is conserved.

EXTENDED EXPERIENCE:

The following question might be posed for those students who can proceed further with these rather abstract ideas about chemical bonds and heat energy. Assuming this model correctly describes what happens on the molecular level between starch and iodine, what can they predict would happen to the temperature of a system when starch and iodine come together to form the bond? They have been learning that when bonds form, heat energy is given off. Thus the temperature should increase. An enterprising youngster who can handle chemicals properly can try the following: Place about 1 or 2 droppersful of tincture of iodine (as supplied, not diluted) in a 1-oz plastic cup. Insert a thermometer. The plastic-backed, -20°C to +50°C thermometers are adequate. Be sure the bulb is immersed (trim off some backing on the bottom if necessary) and read the temperature. Then add 1/2 teaspoon of cornstarch powder and stir. The temperature will rise a few degrees. A deep blue-black liquid will form which may be difficult to stir. If more starch is added, the temperature may rise a bit more as more of the complex is formed, but the mixture will be very thick. However, the increase in temperature should be further confirmation of the model.

Minisequence III
Copper: A Structural Unit

It is the intent of Minisequence III to develop culminating experiences for the conceptual scheme, Structural Units of the Universe. As described in the introductory material, this scheme is concerned with the belief that the universe and all the objects found in it are made up of discrete units of matter. However, the number of truly different "building blocks" is actually limited. How far down in size or dimension do we go in identifying these unit building blocks? For the purposes of the COPES curriculum, it will be the atom. Although the term *atom* is not essential, the concept of a more fundamental unit of matter compared with the molecule will be introduced and developed in this sequence.

Starting in the very early grades children considered the parts of which objects are made. The first Topic in Grade 3 was devoted to developing this idea, beginning with a consideration of objects whose parts could readily be seen and then going on to a consideration of objects where the parts could not be seen but whose presence could be inferred by their interaction properties. In Grade 4 the concept of the molecule as a structural unit of matter was introduced. Experiences in Molecular Sieving in Grade 4 then introduced children to molecules of different sizes, only some of which could pass through the walls of a membrane. In addition they inferred that this unit of matter was the building block of solids and of the gases which could result from the evaporation of liquids. Some of these molecules could be detected by their distinct odor or color. In Grade 5, the notion of a structural unit of matter was extended to the building blocks of living systems, the cells of plants and animals. The concept that a structural unit of matter could itself be composed of still smaller units was introduced in the Cell sequence when the children considered components within the cell.

The intent of the present Activities is to refocus attention on the molecule and then to consider the more basic units making it up. Although there are thousands upon thousands of different kinds of molecules, there are only slightly over 100 different kinds of atoms, or elements, in the universe. Combinations of atoms of these different elements joined in various ways make up all matter. In this case, the children will investigate in more detail the structural unit introduced in the previous Minisequence, the molecule of blue vitriol, to discover a fundamental component of it.

What properties are used to characterize particular substances?

The shape of crystals are characteristic of particular substances, the odor of the gas molecules, the color of the solid crystals or the solution it forms, and the melting point of the solid. The molecules of a particular substance can also be characterized by particular interaction properties. As the children found in the previous Minisequence, blue vitriol interacts with heat energy to release water molecules. Thus they have begun to recognize that the molecule of a particular substance may be made up of parts, and to recognize that if the parts are changed, then the properties will also change. All the properties of a particular substance as exhibited by its collection of molecules depend on the make-up of that molecule. If the make-up is changed in any way, the properties will change. Thus, specific properties can be used to test for particular materials. Conversely it can be reasoned that if properties change, we now have a different molecule--its make-up has been altered either as to the addition or loss of a component part or a change in the number of components: The interaction of blue vitriol with heat energy resulted in the loss of water. The end product had very different properties--e.g., it was a different color (white). Thus the blue vitriol must have molecules of water as a basic component or building block. Without the water, it is a different substance.

In Minisequence III the children discover that blue vitriol contains, besides water molecules, units of copper. During another type of interaction, they will find the units of copper "coming out," just as the water molecules came out when heat energy was added. They will observe that this resulting molecule also has very different properties. Using criteria that they had developed before to identify the blue vitriol molecule, such as color and crystal shape, they will find that these properties are no longer exhibited. Without the basic unit of copper in it, it is no longer blue vitriol. Fortunately, there are certain properties which can be observed which depend solely on the atom or atoms present--and not on the molecule of which it is a part. One of the properties is its flame spectra, which is exhibited by atoms whether alone or in combination. Sodium, whether alone as the metal or in table salt (sodium chloride) or baking soda (sodium bicarbonate), will produce a brilliant yellow flame when sprinkled over a flame. The yellow is characteristic of the atom of sodium. The same is true of copper. Whether it is free as a piece of copper metal, or in blue vitriol, "white" vitriol, or any other copper salt, a characteristic green color is produced in a flame. Thus this property can be used as a test for the presence of the copper atom.

In the first Activity, "The Shape of Things," the children are reintroduced to the property of crystal shape being characteristic of a specific substance. Their observations reveal the differences in crystal shape among substances, as well as the fact that for a given substance, whatever the size of its crystals, their shape is the same. The children find that, at least for some substances, the crystal shape and color provide unique means of identification.

In Activity 2, children begin to pursue the components of blue vitriol. What may it contain other than molecules of attached water? They find that when an iron nail is placed in a solution of blue vitriol, changes take place. An interaction occurs in which a pinkish red substance appears and the blue color of the solution disappears. They are led to the conclusion that the nail becomes coated with copper; the blue color of the solution disappears because the copper is removed from it. The iron takes the place of the copper atoms in the blue vitriol, resulting in free copper and a salt--iron sulfate. A model of this is developed by the children in the next Activity, where they also perform some experiments designed to test their hypotheses based upon the model. If their conclusions about this interaction are valid, the iron nail should be losing matter. This is verified when they find a loss of weight in the nail. In addition, they are able to identify iron sulfate on the basis of its unique crystal shape and color properties, which had been observed in Activity 1. Verification of both of these hypotheses strengthens the validity of their model of the interaction. Since the model is based on molecules being composed of subunits of copper or of iron atoms, verification also strengthens the concept of the atom as a more basic building block of matter. Further reinforcement of copper as a structural unit is made as children are introduced to the technique of the flame test characteristic to each elemental atom. Using this property, they can "test" for the presence of copper in a variety of substances and follow the atom of copper whether it is attached to a "partner" in a molecule or free as copper metal.

Finally, in the last Activity, the children reverse the procedure of the preceding activities. Instead of removing the atom of copper from a molecule, they will interact another salt (a silver salt) with free copper metal. Again there will be a replacement interaction. However, this time copper atoms will go into a molecule and release silver atoms. They synthesize a copper salt from the element. The resulting observation and "test" on the products confirms the "movement" of the copper atom from the metal into the molecule. The presence of copper as a structural unit in the newly formed molecule is detected by (1) a characteristic blue color (2) crystal shape (3) the copper flame test and (4) the interaction properties with iron. Thus, by investigating the now familiar blue vitriol molecules further they have discovered that, as unique as it is by itself, it is composed of more fundamental structural units. Besides units of water, it contains units of copper, which can be identified by its properties.

The concepts developed in Minisequence III are as follows:

1. Some molecules are component structural units of larger molecules.

2. A molecule is composed of smaller structural units of matter called atoms.

3. Certain physical properties are characteristic and unique to a specific molecule, e.g., color and crystal shape.

4. Certain interaction properties are unique to a specific molecule, e.g., the characteristic interactions between starch and iodine and between iron and copper sulfate.

5. The physical and interaction properties can often be used to confirm the presence of a particular molecule.

6. Atoms can sometimes be displaced from a molecule and replaced by other atoms.

7. The properties of molecules depend upon the atoms of which they are composed; substitution of a single atom for another will change the properties of a molecule.

8. Substances containing the same kind of atoms as a component part may exhibit certain properties in common, such as flame color and the blue color of hydrated copper salts, based on the presence of this atom.

Activity 1 The Shape of Things

It is the intent of this series of Activities to investigate blue vitriol further. Since its crystal shape will subsequently be used to signal its presence, the children first are reintroduced to the tendency of some substances to form crystals whose shape is characteristic of that substance. Sodium chloride always crystallizes as cubes, no matter what its source. Similarly, cobalt chloride also forms cubes, but its cubes are red. Epsom salt forms needle-like crystals. Sodium bicarbonate and iron sulfate each form characteristic crystals too. So it is with blue vitriol--it forms blue crystals of a shape different from the other substances observed. The children find that although they may vary in size, the color and shape are all similar. Thus the formation of this uniquely colored and shaped crystal signals the presence in the solution from which it came of the molecules which make up blue vitriol. In subsequent Activities, children will use the criterion of crystal shape and color to confirm the presence or absence of particular substances in solution.

MATERIALS AND EQUIPMENT:

1 polyfoam container, 3 qt (3 liter) capacity, unless warm tap water is available in the classroom

plastic wrap

supply of the following; about 1/2 cup of each:

- blue vitriol (copper sulfate, hydrated fine crystals)
- sodium chloride, from several sources, e.g. "kosher" style, free flowing table variety, rock salt (Halite, used as a de-icer)
- epsom salt
- cobalt (cobaltous) chloride, hydrated crystals
- iron (ferrous) sulfate
- baking soda (sodium bicarbonate)

several wide, squat containers to serve as sources of chemical supply

20 narrow wooden dispensers such as popsicle sticks, beverage stirrers, etc.

1 overhead or microprojector (optional)

microscopes, 40X (optional)

tweezers (optional)

For each team of two children:

4 cups, 1-oz (approx. 30-ml), waxed paper or plastic

toothpicks, one for each solution made up

10 glasses, "old-fashioned," 4- to 8-oz capacity, transparent plastic, or glass slides

2 medicine droppers

2 magnifiers

1 glass marking pencil

Also have available for an optional test:

cream of tartar

sugar, superfine

PREPARATION FOR TEACHING:

If warm water is not available from a tap in the classroom, half fill the polyfoam container with warm water at about 40°C. Have some source of water for rinsing the small cups because the children make up several solutions. If tap water is unavailable, provide several buckets with water marked rinse No. 1 and rinse No. 2.

For the first Section, put out a supply of blue vitriol (hydrated copper sulfate) in one or two low, squat containers. Next to each supply container place one or two popsicle sticks, beverage stirrers, or flattened straws which the children can use to measure out the salt. If you use the sticks, pre-mark them 1 cm up from one end to delineate a "unit" measure of the solid, as you did in the previous Minisequence. If you use the straw, flatten a 1-cm length.

When the children take their samples for Section 2, identify them by name. (Continue to use the term "blue vitriol" for the copper sulfate.) Place the different chemicals in different locations of the room to avoid contamination. If they are not to be used immediately, cover each container with some plastic wrap.

In preparation for Section 3, grind or pound up into a fine powder some epsom salt and some table salt, and place these in containers marked X1 and X2 respectively. Also put out some baking soda (sodium bicarbonate). It need not be ground since it is already in the form of a fine powder. Label it X3. Grind or pound up the rock salt and label it X4. Put out the Kosher salt, which is in the form of coarse grains, and label it X5.

ALLOCATION OF TIME:

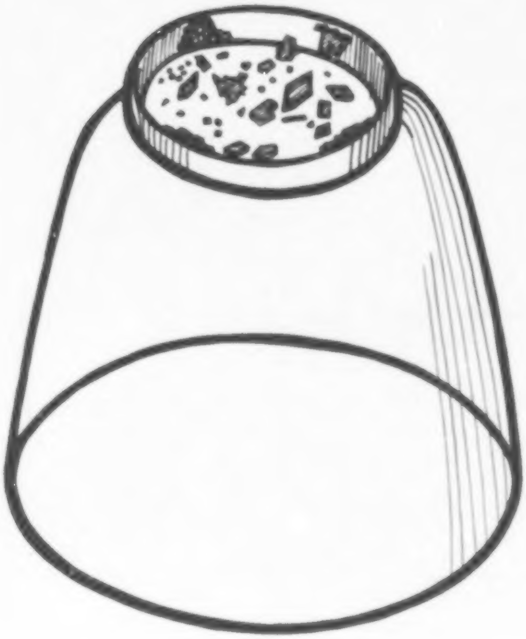
About 1-1/2 hours will be necessary for this Activity, spread over a period of 3 to 4 days.

TEACHING SEQUENCE	COMMENTARY
1. Put some of the blue vitriol crystals in a transparent container and show them to the children. Ask what they have found out about this substance. Have them briefly review their findings.	There should be no doubt in the minds of the children as to the substance you are displaying after the extensive investigations they have completed. The extent of this review will, of course, depend upon the time elapsed since the children completed Minisequence II. Be sure they include such observations as: 1) Adding heat energy drove off water from the blue crystals and resulted in a change in color to white. 2) Upon cooling, the original blue crystals were obtained when water was added back to the dehydrated salt. 3) Reversibility was accompanied by a release of heat energy.
• What will happen if water is added to this substance?	Based on their experience in Activity 4 of Minisequence II they should expect a blue solution to be formed. (Also the solution will cool down, but

TEACHING SEQUENCE	COMMENTARY
	perhaps not perceptibly in this case, as heat energy is absorbed.)
Each team should now get its equipment to prepare the solution. This should include: 1 1-oz cup 1 medicine dropper a polyfoam cup several toothpicks 2 magnifiers	
One member of the team should go to the chemical supply and place two measures of the blue vitriol in one of the 1-oz cups. Then they should half-fill the polyfoam cup with warm water.	Again, a "unit" measure of salt will be that amount which can be picked up on the marked (1 cm) end of the wooden dispenser.
	Warm water is suggested to ensure maximum solubility in a short time for some of the salts to be used later.
Have them add two droppersful of water to the sample.	A dropperful is that amount which can fill the dropper tube to a maxiuum after the air is completely expelled from the rubber bulb and the tube is inserted in the water. With this technique, liquid goes up the dropper tube about half-way. Ordinary droppers then will deliver about 1/2 teaspoon of liquid. If your droppers have a different capacity, adjust the number of droppersful you tell the children to add so that they add a total of about 1/2 teaspoon of water. You may wish to have the children add the 1/2 teaspoon of water with a measuring spoon.
• What do you observe as the water is added?	The blue vitriol will start to form a blue solution as it interacts with the water.
The children can use a clean	

TEACHING SEQUENCE	COMMENTARY
toothpick to stir the solution. As they observe the blue liquid, ask what they believe are the units of matter in the solution.	For one thing there are units of water, or water molecules.
• In addition to the separate water molecules, what is in the solution? Do you think the water molecules attached to the blue vitriol remain attached in solution with water?	Help them come to a realization that hydrated molecules of blue vitriol are present. The fact that the solution is blue would indicate that the hydrate bonds are not broken.
The blue solution, based on their present experiences, is probably composed of molecules of water and of hydrated blue vitriol.	
• What would happen if you let the water evaporate from this solution?	They should expect the blue crystals to reappear when the water "dries up."
• What do they think the crystals will look like?	Those who may have observed some of the "better" crystals may be able to predict that the edges will come together at angles other than those in a square. Some children may remember their observations of blue vitriol crystals in the preceding sequence but they may not necessarily expect the same sort of crystals to appear after evaporation.
Now have the teams obtain a surface on which they can place these solutions so that the crystals can form and then can be readily observed. One surface could be transparent plastic glasses turned upside down. They should pour the solution onto the inverted bottom surface and set it aside to evaporate.	Many so-called "old-fashioned" glasses made of plastic (sold in bulk for parties) have a small elevated rim around the bottom. This rim will retain the solution. Glass slides, plastic transparent dishes, etc., can substitute for the upside down glasses, but if the

TEACHING SEQUENCE



Diamond-shaped blue crystals, like those in the illustration, may appear overnight. They will vary in size, of course, but their shape will be the same as those observed earlier. (Ask the children to observe the angles where the sides of the crystals meet. Even when crystals are elongated, broken, or imperfect, these characteristic angles--together with other properties of the solid such as color--can be used to identify a substance.)

Now ask the teams to compare their crystals. They should notice that in all cases the blue vitriol formed the same shape crystals.

COMMENTARY

dish is too deep, the children may find it difficult to observe the crystals with the highest magnification of their hand lenscs unless they look through the bottom.

If the children will not have the opportunity to view the crystals immediately, they can slow down the evaporating process by placing a thin cover over, but not touching, the solution. This could be another glass nested on the first.

When they are finished, they should rinse out the small cup so it can be used to make other solutions as described below. In rinsing, be sure none of the blue solution comes in contact with the skin.

TEACHING SEQUENCE	COMMENTARY
	The blue vitriol crystals should be saved for later comparison with others.
	Before beginning Section 2, put out additional supplies of evaporating glasses, toothpicks, and 1-oz cups. (If the children will be using the same cups to make more than one solution, they must rinse them very thoroughly in between.) Also set out the supplies of table salt, cobalt chloride, ferrous sulfate, and epsom salt.
2. Do all substances crystallize in the same way?	The children's prior experience may help them to answer this. In Grade 3, Minisequence I of COPES, children formed solutions in water with several different substances and were encouraged to allow the crystals to re-form as evidence that the substance was still present, although the solid particles could no longer be seen once a solution was formed. They also observed the crystals of different substances in Minisequence II.
Have the teams repeat the same procedure with the four other substances put out. Into each of the 1-oz cups, the team should put 2 measures of table salt, epsom salt, ferrous sulfate, and the cobalt chloride. Then add two droppersful of warm water to each salt. Using a fresh toothpick for each solution, stir until all the solid is dissolved.	The children should not touch these substances with their hands, nor otherwise get any of them on their skin, either in the dry form or in solution. They should also be warned not to taste chemicals such as these.
Once the solutions are made, have the children pour them onto the bottom surfaces of four more cups, identify them,	

TEACHING SEQUENCE	COMMENTARY
and set them aside to dry where the solutions will not be disturbed.	
• Now that the solutions are made up, could you tell which solution is which if you don't have the identification?	The cobalt chloride forms a red solution, and the iron sulfate a yellowish one. But the solutions of table salt and of epsom salt are both colorless and cannot be distinguished.
	In a day or two, crystals should appear in all solutions. The time will depend on the temperature and humidity conditions in the area where the solutions were placed. Also, if the solutions were placed in a deep vessel, it might take longer for crystals to be formed.
3. Have the children retrieve their cups and observe the crystals. They should look at the crystals with all three powers of their hand lenses. You might suggest that they sketch the different kinds.	Some children may be quite fascinated by the different shapes of the crystals. If 40X microscopes are available, they can observe one or two of each kind of crystal on a dry slide. Tweezers should be used to shift the crystals to the slide.
• Are all the crystals alike?	All crystals formed from the iron sulfate solution are yellow in color; all crystals from the cobalt chloride solution are red; ahe others are colorless. The shapes of the crystals also vary from one substance to another.
Ask the children to report on the shape of the table salt (sodium chloride) crystals.	All, or almost all, will have formed simple cubic shapes. (Occasionally sodium chloride will crystallize as octahedra.) The faces of the cubes meet at right (90°) angles. If you have an overhead or microprojector, you might find it useful to project some of the crystals of table salt (sodium

TEACHING SEQUENCE	COMMENTARY
	chloride) from different teams to emphasize the uniformity of shape.
• Are all the crystals the same size?	No. Depending on several factors, such as speed of evaporation and the presence of nuclei around which crystals can "grow," some children may get many small crystals, some a few large ones. The shape, however, is that of a cube.
• Is there any other salt which formed the same shape?	The cobalt chloride also crystallizes in cubes; but these cubes are red.
Similarly, have them describe the crystals of epsom salt. How do they compare?	These are not cubes; they form needlelike crystals which appear to radiate out from a core.
• If you were shown these two colorless crystals, could you tell which was epsom salt and which table salt?	From the shape--the cubes would be table salt.
• What do the crystals of iron sulfate look like?	They are yellow and, as in the case of the other substances, are all of one characteristic shape.
Now have them retrieve the crystals formed from blue vitriol. Are they in any way similar to the others?	Only in that they seem to have a set shape; some small ones, some larger. Help the children see that, whether small or large, the same general geometric shape is repeated. Again, the overhead or microprojector can be used.
• If you had very, very tiny pieces of table salt and blue vitriol, what do you think would be their shape?	The discussion should lead to the idea that even in very tiny pieces of a substance, the molecules might be arranged in such a pattern as to produce their characteristic shapes.
Have them set the crystals aside for use in later Activities.	If the air is very dry, you might consider covering them with plastic wrap to prevent

TEACHING SEQUENCE

3. Show the five white substances to the children.

- How could you tell which might be sodium chloride and which epsom salt?

Now let the teams proceed to determine which are sodium chloride and which epsom salt by the shape of the crystals formed on evaporation. First, of course, they must prepare solutions. Advise them to take the same ratios of salt to water they used earlier (2 measures of solid and 2 droppersful of water). The evaporating glasses, of course, will need to be labeled with the identifying number in each case. Glass marking pencils can be used for this purpose.

COMMENTARY

the known hydrates from drying. Also, if it is very humid, substances like cobalt chloride may pick up moisture and become "wet."

Before proceeding with the next Section, be sure the cups in which the children prepared the solutions are rinsed to prevent contamination. Put out the different ground-up samples of sodium chloride, epsom salt and baking soda (sodium bicarbonate) marked X1, X2, etc., as described in Preparation for Teaching, and additional evaporating glasses and toothpicks.

By this time, some children will surely suggest making up a solution and finding out what shape crystals will form.

If there is any material which does not dissolve (e.g., impurities in rock salt), have them filter the small amount of solution. This can be done by cutting out a 3 cm by 3 cm square of paper toweling, folding it in four parts, opening up one section to form a cone, and setting it in one of the small 1-oz cups. Pour the solution to be filtered through the cone and catch the filtrate in a clean cup. The solution will now be clear. Of course if you have regular small funnels and filter paper, use

TEACHING SEQUENCE	COMMENTARY
	them, but cut down the size of the paper to accommodate the small amount of solution.
On examining the crystals the children will find that cubes have formed on the glasses marked X2, X4, and X5 and will probably have identified them as sodium chloride. They will have found the needles characteristic of epsom salt on X1. They may be puzzled by the different looking crystals on X3.	See if they realize that, on the basis of crystal shape, X3 is *neither* sodium chloride *nor* epsom salt. If you wish, tell them that the material is baking soda (sodium bicarbonate). Alternatively, tell them it is one of the following three: sugar, baking soda or cream of tartar and ask them to figure out a way to identify it. Remember that cream of tartar is only very slightly soluble in water.
Confirm that the solids X2; X4 and X5 are all really sodium chloride, but in different forms, some purer than others. Show them the containers of table salt, rock salt and Kosher salt from which you prepared the supply. Help the children to see that since the three solids are really the same substance, they exhibit the same properties, characteristic of sodium chloride. One of those properties is crystal shape.	Can they tell which were purer and which less pure? (cloudiness, etc.)
• What other properties are the same?	Taste, color, hardness, etc.
Relating this experience to the other salts they crystallized, would blue vitriol always form blue crystals with these oblique angles? Would the cobalt chloride always form red cubes?	Yes--the same substance always forms the same shaped crystals. In subsequent Activities in this Minisequence, the children will use the property of crystal shape to identify the presence in a solution of a particular salt, or conversely if they don't obtain characteristic crystals, they can infer that the particular salt is *not* a component of the solution. Crystal shape is one

TEACHING SEQUENCE

The concluding discussion should center about the ideas 1) that different substances may form very different shaped crystals; 2) that no matter what the source, if it is the same substance, the same shaped crystal will form.

COMMENTARY

criterion for inferring the presence of a particular salt.

EXTENDED EXPERIENCES:

1. Both cobalt chloride and the sodium chloride seem to have the same type of patterned structure--cubes--even though one is colorless and the other red. Is this crystal shape characteristic of chlorides? On the basis of but two salts, the children have too little evidence to generalize. If possible, let them work with some potassium chloride (a "salt substitute"). It too will form cubic crystals. But in an optional extension of a subsequent Activity, they will discover that copper chloride does not crystallize in cubes!

2. Some children may be interested in growing larger crystals. They can make saturated solutions of the particular salt by dissolving as much of the salt as they can at a warm temperature, cooling the solution to room temperature, and filtering off any excess solid which may form. Then place it in a cup and insert one of the small "perfect" crystals from their experiment. This so-called "seed" crystal must have well-defined sides and angles. It should then "grow" into a larger one. This procedure works well for the blue vitriol. An excellent reference on this subject is Crystals and Crystal Growing by Holden and Singer, Doubleday, 1960.

3. To reinforce the concept of orderly patterned structure in these different crystals, you can demonstrate the process of crystallization with the aid of the overhead or microprojector. It is recommended that you try out this procedure before you plan to do it in class: Take some saturated solution of a salt and place it on a slide or a flat transparent dish. If the heat shield is removed from the projector, crystallization may start quickly at the edges. If not, place a "seed" crystal in it. The spread of the orderly pattern can be quite exciting to the children, particularly when viewed in a darkened room. This process is similar to solidification from a melt (see Grade 4, Minisequence V, Activity 4).

Activity 2 Loss of the Blue

In Minisequence II the children found that blue vitriol lost its color as heat energy was added. This loss in color, they found, was associated with the removal of water molecules from the solid. Thus they could infer that a solid crystal of blue vitriol contained units of water. Now they will discover that when a solution of blue vitriol comes into contact with iron (in the form of steel wool or a common nail), the blue color also "disappears." Because this occurs in the presence of a water solution, it cannot be associated with the removal of water units. Accompanying the loss in color is the appearance of a new material coating both the steel wool and the nail. After finding that the pinkish coating is not rust, the children are led to the idea that this coating might be copper. Comparison with pieces of copper metal reinforces this idea. The inference that the copper came from the blue vitriol is based on their observations that 1) as the coating called "copper" appears, the blue color fades, and 2) once the solution is no longer blue, interaction with an iron nail produces no coating.

MATERIALS AND EQUIPMENT:

1 polyfoam container, 3 qt (3 liter)

1 pint white vinegar, household variety

several 1/2 teaspoon measures (standard plastic teaspoons bought in packages have this capacity)

a supply of blue vitriol (copper sulfate, hydrated fine crystals) about 1 cup

1 overhead or microprojector (optional)

string, light laundry variety, about 30 feet needed

several magnets

several scissors

several rusty objects (nails, toys, etc.)

several shiny objects made of copper, such as a new penny, wire, pot, etc.

For each team of two:

4 (or more) test tubes, 100 mm x 13 mm

1 cork, to fit the test tubes

several pieces of fine steel wool

4 or more iron nails, 2 in. (5 cm) long, bright common variety

2 1-oz (approx. 30-ml) cups, waxed paper or plastic, or 30-ml beakers

toothpicks, to serve as stirrers

small piece of white paper

paper toweling

magnifier

1 cup, 6- to 8-oz

1 jar to serve as a test-tube rack substitute, e.g., a baby-food jar

PREPARATION FOR TEACHING:

Half fill the polyfoam container with warm tap water (40°C) to be used by the children as their water supply. Set up several stations (to minimize traffic) where children can obtain samples of the blue vitriol crystals. Cover the containers with plastic wrap when not in use. Next to each chemical supply place several marked sticks or straw substitutes to be used for the "unit" measures. In addition, put out several 1/2 teaspoon measures. The commonly available plastic spoons bought for picnics can substitute for the 1/2 teaspoon measure. Their capacity is usually the same.

Ordinary white vinegar can be diluted with an equal amount of water for the vinegar dip. (See page 192.) Put the dilute solution out, along with additional test tubes when the children are ready to start Section 2. Put out the string and scissors where children can have easy access to them.

ALLOCATION OF TIME:

About 2 to 3 hours will be needed for this Activity, extended over a period of several days.

TEACHING SEQUENCE	COMMENTARY
1. Show the supply of blue vitriol crystals to the children. Ask what they know about the properties of this substance.	In addition to its solubility in water, its color and its interaction with heat energy, by this time they should also indicate that its properties include a characteristic crystal shape.
• What did you find was an essential "unit" in these blue vitriol crystals?	Help them relate their prior experiences to the idea that water molecules are essential units in these blue crystals. They apparently are part of the solid structure.
• What evidence did you have that water molecules are essential to the blue substance?	When water was driven off, the blue color disappeared.
• What other units do you think are part of the solid structure?	Molecules of dehydrated salt--some children may say "vitriol." You may want to reintroduce the marble model, used in Minisequence II, which depicted the different types of bonding in the blue vitriol crystals.
Suggest that they try to find out what else besides water is in blue vitriol.	
Have each team get its equipment for this Section of the Activity:	In this Activity, the children can again work in teams of two.
2 test tubes 1 small 1-oz cup 1 piece of steel wool 1 cup for the water supply 1 medicine dropper 1 jar to hold the test tubes	The wad of steel wool should be about 1 in. (25 cm) in size.
One child in the team can put 4 unit measures of blue vitriol crystals into the small	Use the marked wooden dispensers or straws again as a unit measure.

TEACHING SEQUENCE	COMMENTARY
cup. The other can get a supply of warm water in the polyfoam cup. Then, as they did in the previous Activity, they are to add water to the crystals to obtain a solution of blue vitriol in water. This time, however, they should add about 12 droppersful of warm water and stir with a toothpick until all the solid is dissolved. Once the solution is made, have them transfer half of it to one of the small test tubes and the other half to the other test tube.	The solution should about half fill each test tube.
Now each team should get a wad of steel wool and roll it until it is thin enough to be inserted into a test tube. After the roll is inserted into one of the tubes, ask the children to observe what happens.	If the steel wool is fine, the children will have least problems in rolling it.
• Are there any signs of changes?	Within about five minutes, there should be complete interaction of the steel wool and the solution. The children will see a fine coating of a pink substance on the steel wool and the solution will no longer be blue. If the color has not disappeared completely, it will definitely be lighter than the undisturbed solution in the second (control) tube.
Have them pull out the piece of steel wool and carefully place it on a piece of paper towel. What do they notice?	
• How does the liquid compare with that in the other tube containing the "control" solution of blue vitriol?	
• Do you think the solution still contains blue vitriol?	Again leave this an open discussion at this point. Some children may correctly infer that if the solution is no longer blue, it doesn't contain the substance. If it has no color (it may look slightly yellowish), some may suggest that the blue vitriol is now "dehydrated" as in the previous Minisequence. If they mention this, ask them how it could be

TEACHING SEQUENCE	COMMENTARY
	dehydrated when there is so much water present!
2. Show the children a few of the nails. Ask them in what way they compare with the steel wool they just used.	Some children may recognize not only that they are both metals, but that both contain iron.
• How could you tell if both objects contained iron?	By this stage, most children have had experiences with the magnetic properties of iron (e.g., starting in Grade 1 of COPES).
Have several children test both the steel wool and nails with magnets. Since they observed an interaction taking place between the steel wool and the blue solution, perhaps there would be a similar interaction with the nail. Suggest that they test this idea.	Both will be attracted to the magnets.
Each team should take one nail and a piece of string 6 to 8 in. long.	
Have them clean off the surface of the nail by rubbing it with a fresh piece of steel wool and, after tying on the string, dipping it into another test tube containing vinegar. After the dip, have them drain off any excess vinegar on a piece of paper towel.	Many nails come from the factory with a thin coating of oil. This oil will interfere with the interaction they are investigating. Hence the need for cleaning. The string will help them in placing the nail gently into the tube and in retrieving it easily. The vinegar dip, although not essential for the interaction with the copper sulfate in this Activity, will be needed to obtain a copper coating when they test a nail in some copper nitrate in Activity 5. Sometimes, concentration of the salts and acidity play a role in the ability of certain

TEACHING SEQUENCE	COMMENTARY
	chemicals to interact. The copper nitrate solution has to be slightly acidic for copper to appear on an iron nail. Acetic acid, in the form of common household vinegar (5%), is an excellent source of acidity. So as not to introduce a new element suddenly in Activity 5, the vinegar dip is made part of the procedure here with the iron nail. Have them save the tube with the vinegar if they are to prepare other nails.
Once the nail is clean, it should be inserted in the second tube which contains the uninteracted blue vitriol solution.	
• Is anything happening between the solution and the nail?	When the nail is immersed in the blue solution, it will be difficult to observe any change at first.
In about half a minute have them lift out the nail.	
• Is there anything new on the nail?	The tips and edges may show signs of a pinkish deposit. If there does not appear to be much of a deposit, have them reimmerse the nail for another half minute.
Once some definite but thin deposit is visible, they should lift out the nail and place it on a piece of paper towel. Excess liquid can be wiped off with another paper towel.	
• Is there any change observable in the solution this time?	The children may be unsure whether there is a change in the solution. They may rightly point out the need for a control tube of solution with which to make a comparison.
To see if there is a change in the solution under these	

TEACHING SEQUENCE

circumstances, suggest that they try putting a nail into two different concentrations of blue vitriol, one containing half as much blue vitriol as the other. This time they can also set up a control and leave the nails in for a longer period of time.

Have the children discard the solution and rinse out the 2 test tubes (not the one containing the vinegar). Then ask the teams to make up a "master" solution of the blue vitriol crystals. They should place about 1/2 teaspoonful of crystals in the 1-oz (30-ml) cup and add warm water until it is about 5/6 full or until the liquid is about 1 cm from the top. This would correspond to about 25 ml of solution (if there is such a mark). Stir until all, or almost all, of the crystals are dissolved.

One way they could set up solutions of the two different concentrations, so that both have a control, is as follows: pour some of the solution into two test tubes (test tubes 1 and 2) until each is about 3/4 full. Then pour about half the quantities in test tubes 1 and 2 into two empty test tubes, 3 and 4, as shown in the illustration on page 195.

- Are all the solutions in all 4 tubes about the same color, when viewed from the side?

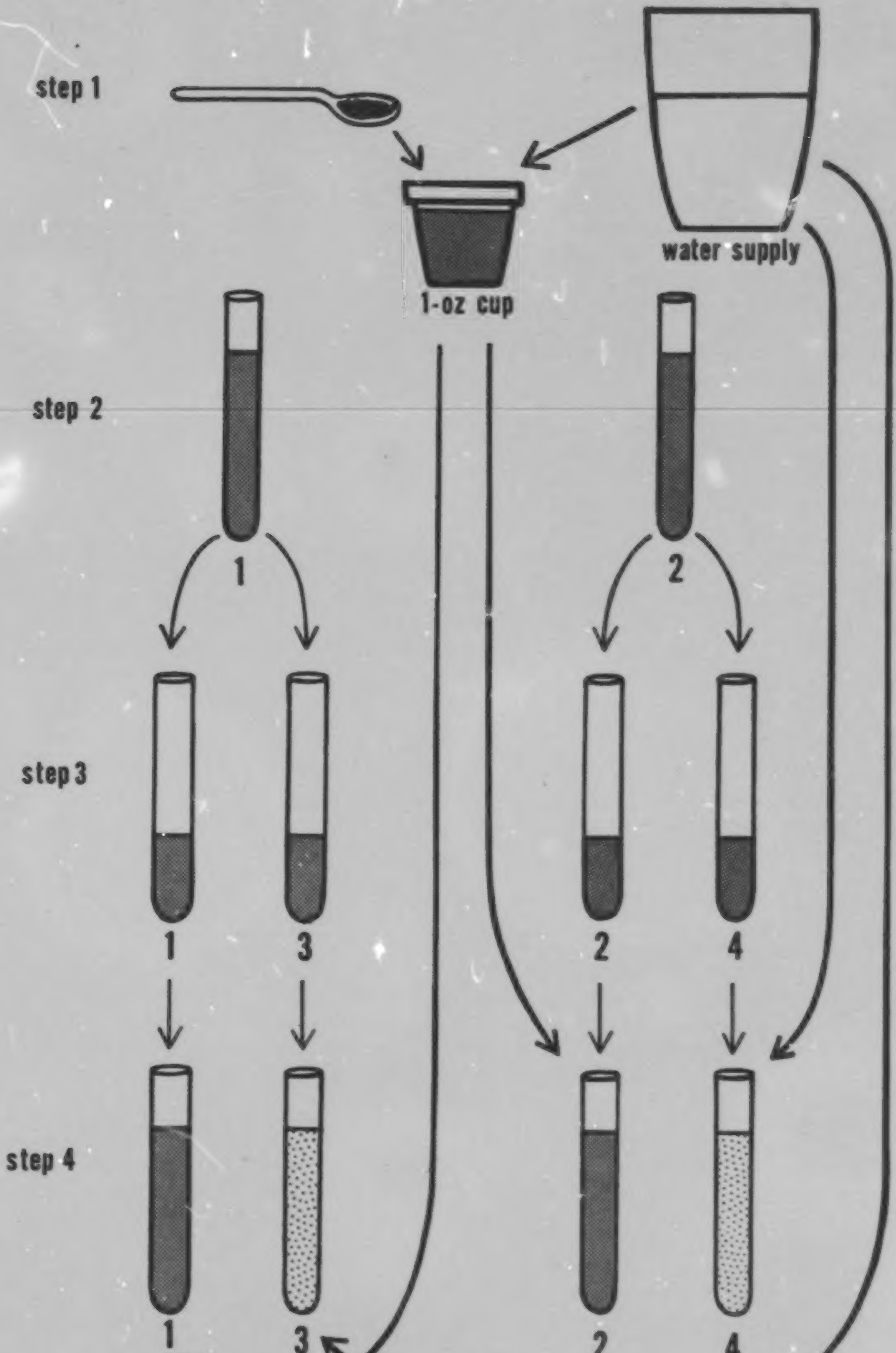
COMMENTARY

Some may think there is a change in the color of the solution, as with the steel wool, but less so, and that the change would be more obvious if the nail were left in the solution longer.

In Grade,5, Minisequence V, Activity 5, a series of eight successive dilutions were made from a master blue vitriol solution. The children observed a distinct gradation in color in the series. Each dilution was made, as in this case, by adding an equal volume of water to a sample from the next more concentrated solution.

Before they perform the actual dilution, ask for their suggestions for making a solution which will contain half as much blue vitriol as the "master" solution. Some may suggest taking half as much solution. If so, tell them you need the same amount of liquid so that a nail can be immersed. Anyway, halving the amounts does not halve the concentration. If some children suggest making up a different "master" solution by taking only 1/4 teaspoon of crystals in the same amount of water, that is perfectly valid. In fact, encourage them to do so and have them compare the color of their solution with that of children who will be diluting from the original master.

They should be, since the liquid came from the same master solution.


step 1
water supply
1-oz cup
step 2
step 3
step 4

TEACHING SEQUENCE

Next, add water to tubes 3 and 4 until they are 3/4 full of liquid. Insert a cork, and invert once to mix. Then add some more "master" solution to test tubes 1 and 2 so they contain the same volume of liquid as they did originally.

Each team should now have 4 test tubes with blue vitriol solution--two with the master solution and two with the dilute solutions. The tubes can be placed in the jar which serves as a rack substitute.

- How does the amount of blue vitriol in the test tubes compare?

After the class discussion, have them prepare two nails to insert as they did before. Then, setting aside one tube of each concentration as a control, the children should gently insert a nail into a tube with the master solution and into a tube with the diluted solution. The tubes can be set aside in the jar for observation on the following day.

3. The next day, have the teams retrieve their jars and observe the contents of the test tubes.

Ask them to describe what they observe and encourage them to be as specific as possible, focusing on the changes which have taken place.

COMMENTARY

Alternatively, they could fill each of the four test tubes to a height of about 1-1/4 in. (3.2 cm) and then mark off double that height on all the tubes. Adding water to that height in test tubes 3 and 4 and solution to that height in test tubes 1 and 2 would accomplish the same thing.

In comparing equal volumes of solution, the tubes with the same colored solution should contain the same amount of blue vitriol; the tubes with the lighter solutions should contain half that amount.

The preparation should include cleaning the surface with steel wool, attaching a piece of string to each nail, and dipping it into the vinegar.

It might be advisable to have each team put a mark on the jar to identify it.

If they remove a nail, be sure they know from which test tube it was removed!

TEACHING SEQUENCE	COMMENTARY
- Are there any changes in the solutions?	It is probable that the more dilute solution will have lost all its blue color; the more concentrated one will be lighter in color. The solutions should be saved for use later in the Activity.
- What do you observe on each nail?	A pinkish coating. If these are new nails, it is likely that the coating will be very adherent.
Three points should emerge from this initial discussion: 1) the more dilute solution has lost all its "blue" 2) the more concentrated solution is lighter in color and 3) the nails from each have acquired a pinkish coating.	
Have the children rinse off the coated nails and dry them. For those nails where the coating can be lifted off, have the children do so after they have been rinsed, and observe the coating carefully.	Not only will it be pink, but it may have a metallic sheen on that part which adhered to the nail wall. However, if a porous or nonadherent coating formed, the deposit will appear very spongy. In those instances (which should be rare with a fresh new nail), it is likely that no blue color will remain even in the more concentrated solution.
- What does this coating look like?	Some children may answer copper right away; many will not. How you guide this section of the Activity will depend on their response. For instance, it it is suggested that the coating is iron, ask how they could test for it. They can test the lifted coat with a magnet. It

TEACHING SEQUENCE

If the children think the coating on the iron nail is rust, the following activities should be taken up.

First, show the children some obviously rusty pieces of iron. Encourage them to view these carefully, using their magnifiers if they wish. Compare the rust on these objects with the coatings on or from the nails.

Then the children can make some rust on the same kind of nails themselves: Each team should take three test tubes, three nails, and a jar to hold the tubes. They should preclean the nails just as they did when immersing them in the blue vitriol and tie a string on each.

Place each nail in a test tube and label each tube (with numbers or letters) to differentiate them. Then place some water in one tube, being sure some of the nail is exposed above the water level. In the second tube, have enough water so the nail is completely covered. Do the same

COMMENTARY

will exhibit no attraction. Thus they can infer it is not iron.

Experience has indicated that many children consider any coating on a piece of iron "rust." Careful examination of the appearance of this coating and comparing it with some actual rust will point up the difference. Note, however, that on long standing, if a piece of iron is partially immersed in a water solution particularly one which is depleted of the blue vitriol, true rust will start to form on the upper part which is exposed both to the solution and to air. (See below.) For that reason, we do not recommend leaving the nails in the solution for prolonged periods of time and certainly never when only partly immersed.

The children can make their own record sheets to describe what went into each tube and to record their observations of the contents after a few days.

TEACHING SEQUENCE	COMMENTARY
for the third tube, but in addition put in about a dropperful of mineral oil. Have them set these tubes aside for a couple of days.	The mineral oil will prevent any of the air above from dissolving in the water. It acts as a "cover."
4. A few days later, the children should take the nails out to examine, along with the nails which had acquired the coating from the blue solutions.	There will be considerable evidence of rust in the partially immersed nail, particularly near the water surface where it was both wet and exposed to air. Where the nail was completely immersed, there will be only faint evidence of rust and there will be none on the nail from the tube to which the oil was added.
• Where the rust appeared, how does it compare with the coating previously formed?	The rust again will appear orange-brown, a different color from the pinkish coating. It also has a different luster.
Help them to see the similarity to the coating on the rusty objects and the difference between it and the pinkish coating.	
• What seems to be necessary for rust to form? How are the conditions different from those under which the pink coat forms?	From their limited experience, only water alone *and* air seem to be needed for the interaction which forms rust. The rust appears on the nail near the *surface* of the water, while the "pink" coating appeared on the nail *inside* the blue solution.
• If the coating is not rust, what is it?	At this point, the children may suggest copper.
Now show them some pieces of copper.	Use a shiny copper penny, a fresh piece of copper wire, or even a shiny copper utensil.
• Is there any similarity between these objects and the coating formed in the blue solution?	Where the deposit is very fine, it will have a rough or matte finish. But where the coating has been smooth, particularly

TEACHING SEQUENCE	COMMENTARY
	when it was lifted off, the coating will resemble the piece of copper metal.
• If the coating on the nail is copper, where did it come from? Refocus their attention on the interactions in the two different concentrations of blue vitriol. Have them look again at the four test tubes, two of which were controls and two of which had nails inserted.	In the subsequent discussion, help the children associate the appearance of the copper with the disappearance of the blue color of the solution. Of course, you might have a child in the class who knows that blue vitriol is copper sulfate! You might find it helpful during the discussion of the relationship between the loss of the blue vitriol and the appearance of the copper coat to display the interaction with a microprojector (or overhead). If so, place a small bit of blue solution on a slide and use a piece of steel wool instead of the iron nail. If the solution is dilute enough, the enlarged image will show depletion of the blue color around the wires of the steel wool as a shiny coppery coat is forming. As usual, it is advisable to try this demonstration out before you do it in the classroom.
• Is there any blue vitriol left in the solution which lost all its blue color after the nail interacted with it?	From the color alone, apparently not.
• What about the other solution, the one that is still blue?	Again based on the color, it probably still contains some blue vitriol.
• If the copper came from the blue vitriol, what do you predict will happen if a clean iron nail is inserted in each of these two "used" solutions?	Encourage their predictions. At this point many should have enough information to be able to predict that a copper coating will again form in the solution that is still blue. There may be doubts about

TEACHING SEQUENCE	COMMENTARY
	the other one, although some may realize that if the copper does come from the blue vitriol, and there is none remaining, then no coating will form.
They should now insert a nail into each of the "used" solutions, after first precleaning them.	If they use the same nails used before, be sure that their surfaces are thoroughly cleaned with steel wool, as with the new ones. This time the steel wool is not needed for any oil coating but to ensure removal of the previously deposited copper so that it doesn't interfere with their observations of any fresh coating formed.
After a few minutes, have the children look at each nail and report their findings. Then suggest that they set these systems aside for the rest of the day or overnight to see if any further changes take place.	The nail in the blue solution will show evidence almost immediately of a coating, but not the one in the non-blue solution.
5. After the children have looked at the two systems again sometime later, ask if there is any difference between the nails.	There will still be a coating only on the nail in the solution which had blue vitriol in it before the nail was inserted.
• Why do you think no coating appeared on the nail in the solution which had lost its blue color?	Since the color of the solution is associated with blue vitriol molecules, there apparently weren't any in the colorless solution. Help them to recognize that the presence of blue vitriol seems to be necessary for the production of the copper coating.
• Then where did the copper come from?	At this point the children can reasonably infer that the copper came from the blue vitriol. You might tell them that the chemical name of this substance is copper sulfate.
• If the copper is no longer	Leave them with this question.

TEACHING SEQUENCE

in the solution, what is in it?

COMMENTARY

Some children simply assume that the liquid is water. Others may have noticed a slight yellowish cast to the "used" solution which they may wonder about.

In the following Activity, the children will develop a model of what might be occuring during the interaction of blue vitriol with the iron nail.

Activity 3 Copper and Iron Change Places

Using colored circles to represent the component units of blue vitriol, now called copper sulfate, the children develop a model in this Activity for the interaction with the iron nail which yielded the copper coat. The model suggests that 1) the solid blue vitriol is composed of units of copper attached to units of sulfate (with water molecules attached to both); 2) an iron nail is also composed of units--of iron; 3) when interaction occurs, iron units from the nail exchange places with the copper units in the dissolved copper sulfate. Thus the model pictures free copper forming a layer on the nail and iron sulfate being the substance in solution--since the copper has left the solution, it no longer is a partner with the sulfate.

In the final Sections of this Activity, children perform two experiments to verify hypotheses based on this model: If the model is useful and valid, then 1) they should detect a transfer of iron out of the nail and 2) they should obtain crystals characteristic of iron sulfate on evaporating the "used" solution. The children test and verify the first by measuring a loss of material in the iron (after several displacements) and the second by comparing the characteristic crystal shapes from the used solution with those formed from iron sulfate in Activity 1.

Thus the children build up experimental evidence that either copper or iron can be structural units within salts; when copper is a unit in a sulfate salt, the solution is blue; when iron replaces it, the solution is colorless or slightly yellow. Thus they can infer that the component structural units in a substance will determine its properties. In the following Activity they will study a property characteristic of a unit (or atom) of a substance no matter whether it is free or bonded to other units--they will investigate some characteristic flame tests.

MATERIALS AND EQUIPMENT:

	balances, Ohaus model No. 1200, or its equivalent, as many as are available
1	overhead projector (optional)
12-18	transparent circles, minimum 3 cm in diameter, of each of 4 different colors (See Preparation for Teaching.)
	iron (ferrous) sulfate, about 1/2 cup

For each team of two:

test tubes from the previous Activity

several new iron nails

additional materials and supplies to make up more blue vitriol solutions (1/2 teaspoon of crystals for each 25 ml of water)

2 magnifiers

2 glasses, "old-fashioned," 4- to 8-oz capacity, transparent plastic, or glass slides

the crystals of copper sulfate and iron sulfate from Activity 1

PREPARATION FOR TEACHING:

In Section 1 you will be developing a model of the interaction between the iron and the copper sulfate with the children. If you have an overhead projector, prepare the recommended transparent colored circles. You may want to assemble some into "molecules of copper sulfate." (See page 207.) Circles of colored construction paper can also be used effectively on the "sticky" type of bulletin board. Of course, colored chalk on the board could be used too.

ALLOCATION OF TIME:

About 3 hours will be needed for this Activity. Again, it will extend over a period of several days.

TEACHING SEQUENCE	COMMENTARY
1. If necessary, briefly review with the children what they observed when a clean nail was allowed to interact with the blue vitriol solution.	A pinkish coating, which appeared to be copper, was formed in all instances.
• What evidence was there that the copper came from the blue vitriol?	It could be inferred that the copper came from the blue vitriol because the copper appeared as the blue color

TEACHING SEQUENCE

- What, then, are the units that seem to make up a molecule of blue vitriol?

The children at this time should see that, besides water, the blue vitriol molecule probably contains smaller units within it called "copper." Help the children come to the idea that copper is an essential unit within the blue vitriol. From its chemical name, copper sulfate, the children may recognize that something called "sulfate" is also part of the molecule.

On the chalkboard or overhead projector, draw the model they had developed for blue vitriol units in Minisequence II. As you discuss what the children have just learned, alter the model. Keep the attached water molecules, but instead of only one central unit draw in circles depicting copper units and sulfate units. The water molecules can be attached to both. The illustration shows one way this could be

COMMENTARY

disappeared from the solution. Also, no coating was formed on a nail in a solution from which the blue had disappeared. It might also be added that the copper coating did not form on the nail under any other circumstances than when the nail was in the solution containing blue vitriol--for instance, putting the nail into water alone seemed to produce only rust, if anything.

The children know that water molecules are a necessary part of blue vitriol--without it, the substance is not the same, as evidenced by the fact that it is no longer blue. Similarly, when the copper is removed from the substance, it is no longer blue: the solution from which no further copper coating could be formed on the nail was clear or slightly yellowish.

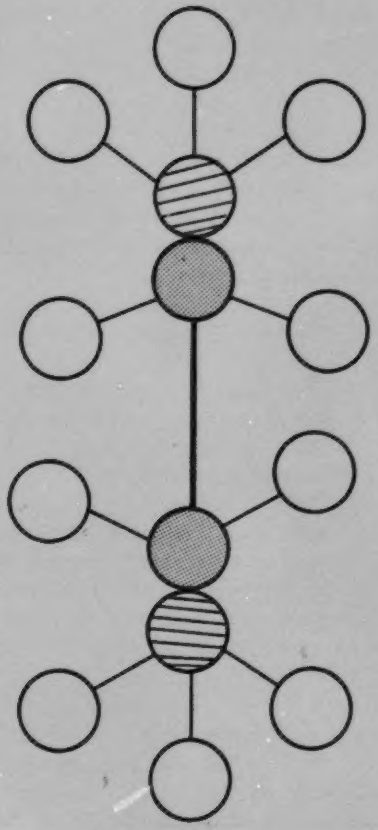
Actually sulfate is a "compound" unit called a radical, which contains several atoms--in this case, one atom of sulfur and four of oxygen--but this is not pertinent to the development here.

If you will be using the overhead projector and transparent circles described below (see page 207), you may want to use the same circles here.

Actually, analysis has indicated that in the case of copper sulfate, four water molecules are attached to the

TEACHING SEQUENCE

represented.



Tell the children that, with the information they have gathered, they may be able to develop a model which would help to explain what happens to the units which make up the nail and the copper sulfate when they interact.

This part of the Activity might be continued by projecting an image of one of the

COMMENTARY

copper and one to the sulfate but, again, the children have no evidence of this and for purposes of the present discussion it doesn't matter.

If some children wonder about the difference in properties between copper metal and copper sulfate, remind them of the difference in water when it is "free" and when it becomes bonded in hydrated salts. In hydrated salts at room temperature, is there any evidence of the physical properties we associate with water at room temperature? Similarly, when copper is bound up with sulfate, the observable properties will not be that of copper alone (even though the mode of chemical bonding is not the same).

Just as with the marble model in Minisequence II, the model they will consider need not be the only possible one. The requirements are that the model explain the observed facts and be useful in predicting other events. If it does this effectively, it is a good model.

TEACHING SEQUENCE	COMMENTARY
blue copper sulfate crystals grown by the class in Activity 1.	Use the overhead projector. As previously recommended, check the operation before you demonstrate it to the class.
Add some water to the solid and have the children observe the slow spread of the blue of the copper sulfate through the surrounding liquid.	
• What happens to the molecules of copper sulfate when water is added to the solid?	The molecules of copper sulfate will have the bonds holding them in the solid broken as they become part of the mobile liquid. (See Activity 1 of Minisequence III in Grade 5 of COPES.)
• Then how could we represent the units in the copper sulfate solution?	As the children discussed in Activity 1, the solution contains molecules of water and of hydrated blue vitriol (if it were not hydrated, the solution would not be blue). Thus, to represent the solution, a drawing or other representation could be made of separate copper sulfate molecules together with water molecules.
Using several transparent circles of three different colors, if you are working with the overhead projector, arrange the circles to represent two or three separate molecules of copper sulfate and a few molecules of water. (If the molecular model of copper sulfate is still on the overhead, break the pattern apart and distribute the units.)	As indicated in the materials list, circles of different colored construction paper could also be used on a sticky bulletin board. This model construction can even be made on the board with colored chalk. Use whatever medium you are most comfortable with.
If possible, move the units about to represent their freedom to move.	Some children may be aware that the molecules in solution move about. There is considerable mobility in the liquid, as

TEACHING SEQUENCE

Now show the class the circles of a fourth color. Suggest they be used bo represent the iron nail.

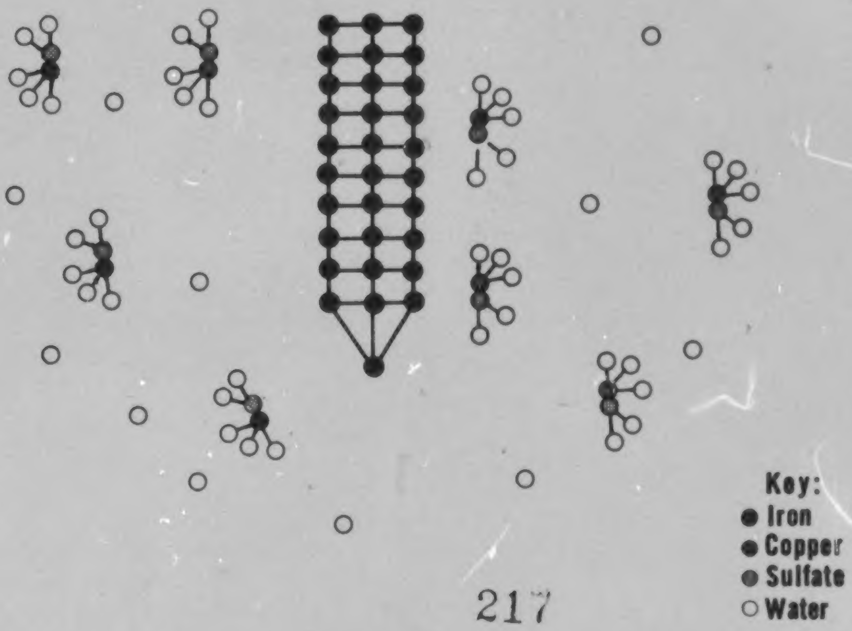
- How should these circles be arranged?

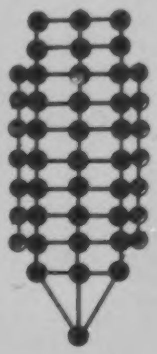
You might arrange the circles in three rows as shown. Place them among the copper sulfate and water units.

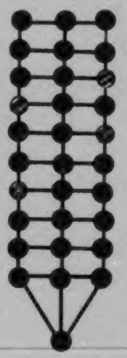
COMMENTARY

compared with a solid. This difference between the solid and liquid states was extensively developed in Grade 4, Minisequence V and Grade 5, Minisequence III. They will probably not be aware that the copper and sulfate "ions," with their attached waters, dissociate in solution. However, it is not necessary that they know this.

Since the iron nail is a solid, these circles should be arranged in an orderly array with bonds connecting them.



TEACHING SEQUENCE	COMMENTARY
Now ask one of the children to come up and show on the model what the nail looked like after it was in the blue solution for awhile.	Often children will take the colored circles representing the copper and line them up along the nail representation, with or without the attached water, as shown below. This seems quite logical to them because in many cases the sheath of copper coating could be peeled off. 
• Is every one satisfied with this model of the interaction? • Is the nail really necessary in this model? Couldn't the copper come out as a solid on the surface of anything--for instance, a toothpick?	The children may be brought up short by such questions. One or two may want to actually put a toothpick into a copper sulfate solution and see if a copper coating appears on it! If so, encourage them to do so and take up the remainder of the discussion of the model after the results are in.
If no one mentions it, you might ask if anyone noticed any change in the iron nail.	Some children may have noticed that 1) the nail was no longer shiny, 2) it may have appeared pitted, and 3) the nail re-inserted for a second coating might have appeared thinner. However, don't press for these responses.
	Here you are focusing on the

TEACHING SEQUENCE	COMMENTARY
	essential nature of any interaction--that is, as two substances interact, changes will appear in both as a result. (This is also true as energy interacts with matter: not only do the properties of matter change, but the energy will often change in form.)
Ask them how they might change the representation to show the iron nail as taking part in the interaction.	If no child suggests it, you may have to do an exchange of a copper "atom" for an iron "atom." At first, set up the model so that about half the available copper units are exchanged for iron on the surface of the "nail," as shown below. In other words, a few copper atoms should be put where iron atoms are and the iron atoms that are displaced put where the copper atoms were.
Ask the children to consider this model for the interaction.	
• What happened to the color of the solution when enough iron nails were inserted?	The color disappeared.
• Did you have any evidence of copper left in the solution when there was no more blue? Did an added nail form a copper coat?	No--once the blue color was gone, the copper coating did not appear.
• Do you think this	Help the children to recognize

TEACHING SEQUENCE

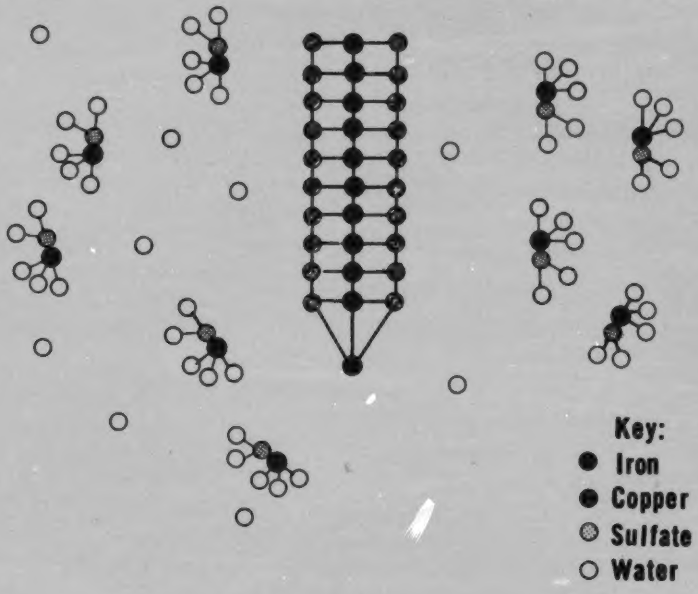
representation is a good model of the system which was no longer blue?

Now have a child show how the model should be changed to represent the solution that had had all its copper removed.

COMMENTARY

that at that stage the evidence was that there was no longer any copper in solution.

The outer columns on the iron nail should have all the circles of "copper" while surrounding it the sulfates are still there but now there are units representing iron with them.



- If copper and iron change places completely, what is the substance dissolved in the water?

Before going on to test the model, you might want to ask the children to make their own representations of this model using whatever media they wish--buttons, sequins, tiddly winks, etc. This could be done at home.

According to the model, the dissolved substance would be iron sulfate. Note that this illustration simply shows that iron and copper have exchanged places, based on the children's inferences. The illustration shows 5 attached waters as with copper sulfate. Although iron sulfate may have as many as 7 attached waters, this is not germane to their model building.

TEACHING SEQUENCE	COMMENTARY
2. With the model of the interaction between a nail and copper sulfate still on display, ask the following questions:	
• If the copper coating does not just lie on the surface of the nail but actually takes the place of some of the iron, how would this affect the amount of iron in the nail?	Encourage the children to develop ideas on how their hypotheses and predictions could be checked out.
• How might the nail be represented after you removed the copper coat?	As this question is raised, take away the circles representing the copper coating.
• In this model, how does the remaining iron compare with the original iron?	There would be less iron in the nail after the interaction than before.
• How can you check out whether there is less iron after the copper forms?	Some children may suggest measuring the thickness of the nail after removing the copper coat; some may suggest weighing the nail.
Have the teams set up an experiment to test this prediction. For those wishing to follow any change in the amount of iron in the nail by weighing it, they can use the Ohaus balance, or its equivalent.	Be sure that they plan to weigh or measure the nail *before*, as well as after, the interaction. They can use a millimeter ruler to judge thickness. However, since all they want to test for is *loss* of material, some children may merely want to outline the nail before and after the interaction.
	Whatever balance is used, the nail should be weighed to one-tenth of a gram. A typical 2-in. common nail was found to weigh 3.0 g. (Some children might be interested to see what variability they can detect in the weights of different nails taken from the sample you provide. Such variability in a property for members of a sample was the focus of Activities

TEACHING SEQUENCE	COMMENTARY
	in Grade 5, Minisequence V, "Investigating Populations.")
The teams should make up fresh batches of master solution of the copper sulfate. As before, it will be convenient for them to perform the interaction in a test tube. Thus a string should be tied to the nail after it is cleaned.	They should again use 1/2 teaspoon of the salt in about 25 ml of water. See if the children realize that they must weigh the nail *after* cleaning with steel wool *and* with the string attached.
Have them immerse the fresh nail in the copper sulfate solution and leave it in for a considerable period--all day or overnite. They should then remove the coating of copper and reimmerse the nail until the blue color of the solution is depleted. Then take a *fresh* solution of copper sulfate and continue the process, removing the copper from it as well. Each time the nail is immersed, its surface should first be carefully cleaned of copper.	The children should rinse off the plated nail before handling it, use paper towels to dry it and a small piece of paper towel to help remove the copper. It should *not* be rubbed with steel wool. Rubbing will physically remove some iron that was not part of the interaction with copppr sulfate. After the nail had had its first coating of copper removed, its surface may be "pitted." Subsequent coats will be very fine, nonadherent, and will deplete the blue solutions more quickly.
	Save the first colorless solution obtained.
Once the nail appears to be smaller, they can stop the interactions with copper sulfate. They can then rinse and dry off the nail, remove the copper and weigh what's left of the nail.	As many as three or four immersions may be necessary to obtain an easily detectable loss in weight.
3. While this test of the model is going on, discuss	

TEACHING SEQUENCE	COMMENTARY
with the class their hypotheses about what is left in the colorless (or slightly yellow) solutions after the copper completely coats out.	
• If this model is correct, what would the molecules in the solution be after interaction?	If the copper and iron do indeed change places, there would be iron sulfate in the solution, instead of copper sulfate.
• Could you perform some test which might indicate whether the non-blue solution is iron sulfate?	The crucial insight here is to see that if the color and shape of the crystals which form on drying are the same as that of those formed in Activity 1 from the known iron sulfate, then it probably is iron sulfate.
Using the technique established in Activity 1, have them set some of the solution reserved in Section 2 aside to form crystals.	In addition, some children may want to make a solution of known iron sulfate (from the chemical supply bottle) and see if it resembles the non-blue solution. They should use the same ratio of solid to water that they did in making the copper sulfate solution. Provided the size of the crystals are the same, the solutions will appear similar.
	If the iron sulfate crystals obtained in Activity 1 have stood around too long, some changes may have appeared in them. If so, you might want to have the children evaporate the solution of known iron sulfate (from the supply bottle) and obtain fresh crystals for comparison.
After the crystals are formed and they have made their final weighings on the nail which has been immersed in copper sulfate solution several times. Ask the children to report on their findings.	The crystals will be light yellow and of the same shape obtained for iron sulfate in Activity 1. They will have no similarity to copper sulfate crystals. The nail will have "lost"

TEACHING SEQUENCE	COMMENTARY
	considerable material: After inserting the same nail in 4 fresh solutions of copper sulfate, the 2-in. nail, weighing 3.0 g initially, weighed 2.0 g. It lost 1/3 of its iron. Its thickness was noticeably less.
• Do you have any more confidence in the model now?	Help them to see, if necessary, that the iron apparently did take the place of the units of copper in the copper sulfate solution. It was present as iron sulfate.
• What evidence is there that iron units and sulfate units were in solution?	The similarity in the crystals formed in drying.
• What happened to the copper?	The copper appeared as a coating on the nail.
Now, instead of the circular model representation, write the "word-equation" expressing what they think happened in this interaction.	

COPPER SULFATE AND IRON ⟶ COPPER AND IRON SULFATE

By the final discussion the children should be able to identify not only the different units whose movements they have been following, but also the two different changes noted in this interaction: The copper sulfate is giving up its copper, the iron from the nail replacing it in the molecule.	At the end of this Activity, have the children cover and set aside the nails, the copper coatings, the coated nails, the solutions of blue vitriol, and the used, colorless solutions. They will be needed in Activity 4.

EXTENDED EXPERIENCE:

Some children may want to pursue the interaction of the iron nail with the solution until the nail is all used up. This will happen eventually as fresh solutions of copper sulfate are used. Do not let the nail remain exposed to the air or in a copper-depleted solution, however, or rust will form.

Activity 4 Further Corroboration of the Model

In this Activity the children investigate a property of atoms which reinforces the concept of copper as a structural unit of matter. The children have observed that "free" copper (the metal) has different properties than blue vitriol. The presence of copper in the latter could only be inferred from the appearance of free copper metal on the nail as the blue color of the solution disappeared and from the fact that it did not appear in a non-blue solution. Now, in the present Activity, they investigate a property--the flame test--which is characteristic of the copper unit, no matter whether it is bonded only to itself or bonded to another kind of unit in a salt.

They learn the technique of flame testing with several salts, some of which have a common flame color. Sodium salts, for instance, all exhibit a characteristic yellow flame when heated. The children find that copper salts yield a bright green flame. This characteristic bright green is also obtained from pieces of copper metal such as a wire or a penny. The presence of the unit of copper can thus be verified from the green flame test, whether it is "free" or in a salt. Then they find that the flame that is characteristic of a given salt can be obtained from a solution containing some of the dissolved salt. With this information, the children further corroborate their model of the interaction between the iron nail and blue vitriol. As predicted, they find copper in the blue vitriol solution and in the coating on the nail. In other words, these two substances, which appear so different, have something in common. That something is copper. But no copper units are detected in the solutions from which the copper has been removed.

MATERIALS AND EQUIPMENT:

several metal waste cans

1 polyfoam container, 3 qt (3 liter) capacity or other container for cold water

safety matches if not given to the teams

1 pint ammonium chloride solution (see Preparation for Teaching) or substitute such as a mouth wash containing zinc chloride (e.g., Lavoris)

sodium chloride (table salt), about 1/2 tsp.

sodium bicarbonate (baking soda), about 1/2 tsp.

epsom salt (optional)

supply of the following chemicals; about 1/2 cup each:

- sodium sulfate (Glauber's salt), available in drug stores
- sodium thiosulfate (hypo)
- potassium bitartrate (cream of tartar)
- potassium chloride (salt substitute)
- copper sulfate, hydrated crystals (blue vitriol)
- copper sulfate, anhydrous
- copper chloride* (optional)
- calcium chloride* (optional)
- lithium chloride* (optional)

several wide, squat containers to serve as supply stations for the chemicals, with dispensers

several pieces of metallic copper, e.g. wires, pennies

pieces of iron, e.g. nails

plastic wrap

masking or plastic tape, in dispensers

several new unopened containers of Sterno

several plastic or metal spoons, small

the items produced in the previous Activities, e.g., a copper coated nail, the copper coating removed from the nail, crystals of copper sulfate formed by evaporating the blue solutions, crystals obtained from the copper-depleted solution, etc.

For each team of two children:

at least 10 pieces of heavy duty aluminum foil, about 8 cm on a side

several paper clips, standard (the tinned steel variety)

1 box safety matches (optional)

glass or porcelain cup, dish or beaker (for discarded matches)

several pieces of paper, small

1 cup, 1-oz (approx.) 30-ml, waxed paper or plastic

1 Worksheet III-1

1 test tube holder

*These chemicals would need to be ordered from a supply house such as Fisher or Cenco. Although calcium chloride is available commercially as a de-icer, flame test results with this material are not dependable: it contains other substances as well as calcium chloride. It also is in the form of pellets which would need to be crushed into a powder. A yellowish red flame is obtained from calcium. Lithium chloride yields a beautiful carmine red flame which is very easy to see. This substance would be a nice addition to the list of materials to be tested in Section 2. Copper chloride, which yields the characteristic green flame, could also be added to the list, especially if you plan to have some or all of the children do the Extended Experience at the end of the Activity.

PREPARATION FOR TEACHING:

There are several things which could be prepared ahead of time in order to simplify the procedures the children will follow in performing flame tests. Instead of using a whole container of Sterno, each team will use a small glob on a piece of aluminum foil. This means only a very small source of heat, a small flame, and if any contamination occurs by the chemical tested, the entire can of Sterno need not be discarded. If you wish, and have helpers, you might "prepackage" the Sterno: place an amount the size of a 3/4-in. marble (scoop it out with the spoon) on one piece of foil, cover with another piece of foil, and crimp the edges together. This is the package to be used for each test. Each team will need at least 10 of these.

For use in Section 2, prepare several low, squat containers of various chemicals. Label the containers X1 to X7 and fill them as follows: X1 might contain potassium chloride, X2 anhydrous copper sulfate, X3 calcium or lithium chloride, X4 sodium sulfate, X5 cream of tartar, X6 copper sulfate, and X7 "hypo" (sodium thiosulfate). Copper chloride could be included as X8, if you wish. Of course, the order can be varied. It is most important not to let the various chemicals become contaminated with each other. The teams will take each sample of solid to be tested on a separate piece of paper, which should then be discarded. Planning the placement of separate stations of chemicals ahead of time will minimize traffic problems.

The test for some forms of copper requires a dip into a solution such as ammonium chloride. This can be prepared ahead of time by dissolving several tablespoons of ammonium chloride in a quart (liter) of water. Ammonium chloride, often sold as sal ammoniac, is available in drug and hardware stores. It can be stored in a plastic or glass container covered with plastic. If a screw top is placed on the jar, be sure no metal is exposed. Pre-cover it with plastic wrap. Some mouthwashes can readily be substituted for this solution if they contain certain additives, such as zinc chloride, which tend to produce a slightly acidic solution. Lavoris is one of those commercially available.

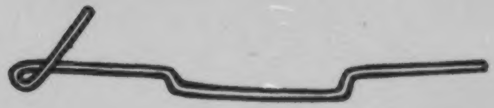
ALLOCATION OF TIME:

This Activity will require about 3 hours, exclusive of the Extended Experience with copper chloride.

TEACHING SEQUENCE	COMMENTARY
1. Bring out some ordinary table salt. Ask the children what they recall about its properties.	They should remember the characteristic cubic crystals formed in Activity 1. In addition, it is white and soluble in water.
Now show them the sample of baking soda.	
• In what way is it similar to table salt?	It is white, and also is soluble in water.
• What about the crystal shape it formed?	The crystal shape is quite different.
Set up one of the flame test units for all the children to see: place a bit of Sterno the size of a marble on the foil. Tape the foil to the desk top and have the second piece of foil along side, together with a cup of water.	The second piece of foil can be used to snuff out the flame if there is leftover Sterno

TEACHING SEQUENCE	COMMENTARY
	when a particular flame test is finished. The water will be used to extinguish the discarded matches.
Light the Sterno.	
• Can you see the color of the flame?	If the room is darkened a bit, the flame will be more easily seen.
Now sprinkle some table salt on the flame. To do this, scoop up a few crystals on the back of the handle of a spoon and tap it lightly over the flame.	To avoid contamination, don't touch the crystals with your hand.
• What do you see?	The flame becomes bright yellow and will continue to burn yellow because of the salt that was sprinkled on.
Set up a second foil with Sterno and light it but this time sprinkle some baking soda on it.	You will have to use new Sterno set-ups for each test. The flame test is very sensitive particularly for sodium salts; sprinkling even a little sodium salt on the Sterno in this fashion will continue to give the characteristic yellow color for a long time.
• What happens to the flame?	It also becames bright yellow.
	Be sure you snuff out the flame when you are finished observing it. Use the second piece of foil and place it over the flame. To discard used set-ups, merely wrap the foil up and around and throw them away. (Have metal wasts cans distributed around the room for the children to use later.)
In addition to being white and soluble in water, table salt and baking soda have another property in common: both substances cause a flame to	Some children may say that any powder will do the same. If

TEACHING SEQUENCE	COMMENTARY
turn yellow.	so, bring out the epsom salt which also is white. Sprinkle this on another flame test set-up. Not all elemental units will produce a readily visible flame under the simple conditions in this Activity. Epsom salt (magnesium sulfate) does not.
• What does the same flame test suggest about table salt and baking soda?	Perhaps they both contain the same thing.
Ask the children if they know the chemical name for table salt. Then ask if they know the chemical name for baking soda. If no one knows, tell them it is called sodium bicarbonate.	Many will know that it is sodium chloride. As you discuss these solids, write their chemical names on the board.
• What do they have in common?	Something called sodium.
• If table salt consists of units of sodium and chloride, what are the units making up the molecule of baking soda?	Presumably, sodium units and bicarbonate units. Note that we are now focusing attention on the components of certain molecules. The name atom need not be used because in the salts investigated, the unit other than the metal atom (copper, iron or sodium) may itself be composed of several atoms, forming a radical (e.g., sulfate has one sulfur and 4 oxygen (SO_4); bicarbonate has 1 hydrogen, 1 carbon and three oxygens (HCO_3), etc.). It might be confusing to use the term atom for copper and not for sulfate. The concept of a unit within the molecule is what is being developed in the Minisequence.
2. Suggest that the children try using the flame test to see if any of a group of substances are made up of the same kind of units.	The various substances, each with its identifying number, should be distributed around the room at this point.

TEACHING SEQUENCE	COMMENTARY
Before they start, show them another way to test in the flame--with a paper clip loop, like the one shown at the right. The loop part should be small enough so a crystal or two will sit on it (and when they pick up solutions later the liquid will cling there).	
Show the class how to dip the loop into some salt, pick up the crystal and hold it above the Sterno flame.	The clip will not get too hot to hold.
The children can perform this part of the Activity in teams of two. One team member can prepare a Sterno set-up unless you have prepackaged the Sterno. The aluminum foil should be secured to the table top with small pieces of tape (masking or plastic) to prevent the unit from being blown off.	They should go to the supply of Sterno, scoop out a small bit, place it on the piece of aluminum foil, cover it with another piece, and take it over to their work area. The foil will not get hot enough to damage the desk top.
The other teammate should go to one of the supplies of salts and get a small supply on a piece of paper.	He or she can take the standard "unit measure" with the dispenser stick or straw.
If the children will be lighting their own Sterno, each team should have a box of safety matches. It should be kept well away from the flames. Have them half fill a cup with water for the discarded matches.	There are certain simple, basic precautions in working with the Sterno in this fashion in addition to the general precautions in working with flames indicated in Minisequence II: 1) If Sterno accidentally gets on the hands as it is being transferred, wipe them well with paper towels before striking a match. 2) Never put additional pieces of Sterno on a foil if there is still a flame. Blow it out first.

TEACHING SEQUENCE

COMMENTARY

3) Keep the Sterno covered when it is not being used. This will prevent evaporation and possible contamination which will obscure the flame tests.

4) Discarded matches should be put into the cup of water.

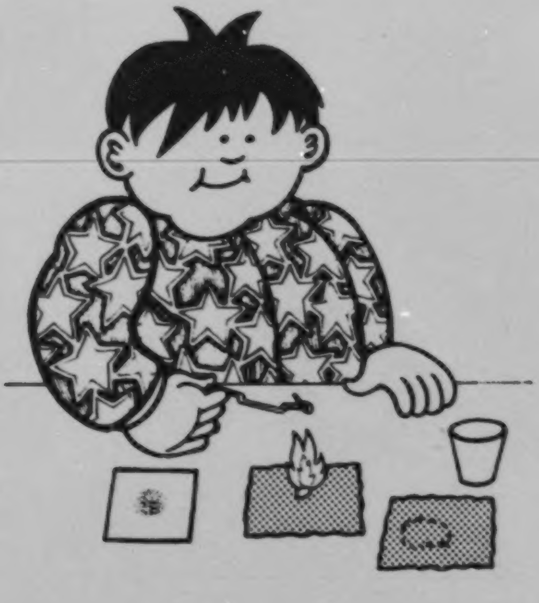
Have the children make a loop out of a paper clip and practice lifting up a small bit of solid with it.

When they are ready to test the salts, have them light the Sterno and observe the color of the flame.

Be sure there are no drafts at the work areas.

If uncontaminated, as it should be, the Sterno will burn with a very light blue flame. It will be easiest to see if the room is darkened somewhat.

Now place the loop of the pin containing the piece of salt in the upper part of the flame. What happens? The results can be recorded under "color of flame" on Worksheet III-1.



WORKSHEET III-1 Name:

SUBSTANCE NUMBER	COLOR OF FLAME	UNIT IN COMMON WITH	CHEMICAL NAME	
			Unit Responsible	Partner

TEACHING SEQUENCE	COMMENTARY
Next, with the team members reversing their roles, a second setup should be prepared. Using a new paperclip, have them test another of the salts, and so on.	To avoid contamination, a fresh paper clip should be used for every test.
As they go along, they should notice that some salts produce the same color flame as others. The number of numbers of the substances which seem to have a unit in common can also be recorded on the Worksheet. An example is shown on page 226.	
When the children have finished testing all the salts, ask them to describe their observations of each one.	There will probably be general agreement on the color of the flame obtained in each case with the possible exception of the potassium salts (X1 and X5). The flame color for potassium is similar to the flame color for Sterno--thus children sometimes report observing "nothing." See if the children suggest resolving arguments about this flame by comparing it with a "control" flame of Sterno alone.
• Which substances seem to have a unit in common?	As indicated by their flame color, the following substances contain the same kind of unit: X1 and X5 (light violet), X4 and X7 (yellow), and X2 and X6 (and X8, if included) (green).
• What unit do you think caused the yellow flame of X4 and X7?	Since the flame color is the same as that obtained from sodium chloride and sodium bicarbonate, many children correctly infer that X4 and X7 must also contain sodium.
Identify substances X4 and X7 as sodium sulfate and sodium thiosulfate (hypo). This information can be recorded on the Worksheets.	
What do you think caused	Most children will have

WORKSHEET III-1 Name: Hernando

SUBSTANCE NUMBER	COLOR OF FLAME	UNIT IN COMMON WITH	CHEMICAL NAME	
			Unit Responsible	Partner
X1	violet?	X5?		
X2	green	X6, X8		
X3	red			
X4	yellow	X7		
X5	violet?	X1?		
X6	green	X2, X8		
X7	yellow	X4		
X8	green	X2, X6		

TEACHING SEQUENCE	COMMENTARY
the green flame of X2 and X6 (and X8)?	recognized X6 as blue vitriol; they may or may not have recognized X2 as its anhydrous form. If not, or if they only suspect that it is, suggest that they add water to see if it will rehydrate to form blue vitriol. The response then will probably be that copper is the unit responsible for the green flame.
	At this point, you might provide them with the names of the other substances they tested so that they can verify their other inferences about substances which did (or did not) have units in common.
• How do you know that the green flame is not caused by the sulfate unit in copper sulfate?	Since a yellow flame, and not green, was obtained from sodium sulfate, it is reasonable to assume that copper is the component of the copper sulfate molecule that causes the flame to turn green. If they tested copper chloride, which also yields a green flame, this is additional evidence that it is the copper that is responsible.
3. What about copper which is not bonded to anything else? If no one has already suggested it, show the children a piece of copper wire (or a penny) and suggest that if they get the green flame color with this, it will provide still more evidence that it is copper which is responsible for the green flame obtained with copper sulfate.	
• What do you predict will happen if you heat these plain copper units in the flame?	The children may or may not expect the flame to be green.
Suggest that they try this but	

TEACHING SEQUENCE	COMMENTARY
tell them that since the flame color is not as easy to get as in the case of sodium, or even copper sulfate, they have to go through an extra step.	
Each team should get a piece of copper wire or a penny, a test tube holder, and half fill the small cup with the ammonium chloride solution.	If the wire and/or the penny are tarnished (covered with oxide), the children should clean them with steel wool.
After they have prepared a new Sterno setup, have them light the piece of Sterno, grasp the copper wire with the test-tube holder, and heat it in the flame.	Because copper is a much better conductor of heat than the iron in the paper clip, the end in their hands may become too hot to handle.
• What happens?	It is most likely that no special color in the flame will appear, except for some sparks from pieces of steel wool which may be present.
Now have them dip the hot end of the copper wire in the ammonium chloride solution and reinsert the wire in the flame.	
• How does this flame compare with the ones obtained from copper sulfate?	A beautiful, intense green flame will form. It will be very similar to the fleeting one obtained with the solid copper sulfate, both hydrated and anhydrous.
• What unit is producing the green flame in this case?	The copper in the copper wire. If some children quite reasonably consider that the ammonium chloride caused the green, have them perform the following: Take a paper clip loop, heat it in the flame (no special color); immerse the hot clip in the ammonium chloride and reinsert

TEACHING SEQUENCE	COMMENTARY
	in the flame. No special color will be produced. It is only with the copper wire that a green flame appears. (The function of the ammonium chloride is to form a small amount of copper chloride on the surface. Copper chloride volatilizes readily in the Sterno flame and it is that which produces the green color most readily.)
Help the children to recognize that what they are observing--the green flame--is a property that is characteristic of copper whether it is bonded to other structural-unit "partners" or not.	
4. Now reintroduce the model the children had been developing of the interaction with the iron nail. Could they use the flame test to find out if copper really does come from the copper sulfate solution to form the pink coating?	
• How would you test the pink coating?	The pink coating could be tested in the same way the wire or penny was tested. If the same green flame is obtained, they can be even more certain that the pink substance is copper.
• How would you test the copper sulfate solution? What happens to molecules of a salt when it dissolves in water? Are they still there?	Their experience has led them to believe that the molecules of a salt go into solution. The evidence was that the salt crystals re-formed when the liquid dried.
• Do you think a table salt solution would give a yellow flame test?	The children may be uncertain about this.

TEACHING SEQUENCE	COMMENTARY
Make up a table salt solution by placing some measures of salt in a small cup and adding water until a solution is obtained. Then take a fresh paper clip, dip it into the salt solution, and hold it over the solution.	The flame will be distinctly yellow.
• Are there sodium units in the table salt solution?	Apparently so.
• Would you predict the blue vitriol solution will give the green flame test?	Yes.
• the coatings?	Yes.
• the nails?	Not the uncoated one.
• the non-blue solution resulting after interaction?	No. It was inferred from the model that iron sulfate was in the solution.
Ask the children to record their predictions as to which of the substances will give the green test indicating copper units. Then have the teams retrieve the iron nails, the copper coatings, the coated nails, the solutions of blue vitriol, and the "used" solutions which had lost their color, from the previous Activity.	
The coatings and the nails should be tested by first heating them, then dipping them in the ammonium chloride before reheating in the flame.	In working with the solids, a flame setup may not have to be replaced but simply replenished with more Sterno. If the children feel they have contaminated the Sterno--if they are unsure of the test--they can get a new setup.
In the case of the solutions, the same procedure should be applied: Heat the paper clip loop, dip it into the solution, then heat it, dip into the ammonium chloride and reheat. If the green color does not appear immediately with	Let the children work at their own pace with these tests. You may wish to have them work independently during an "open" period. If you do, be sure

TEACHING SEQUENCE

the blue vitriol, repeat the steps.

The results, which they should make a record of, will be as follows:

Object	Green flame?
coated nail	yes
nail	no
coating	yes
blue solution	yes
colorless solution	no

As expected, the pink coatings and the blue vitriol solution do indeed yield the characteristic green flame. These two substances, which appear so different, have something in common--copper.

COMMENTARY

there will be a minimum of traffic in their work area and that all safety precautions are observed.

Thus the original interaction,

BLUE VITRIOL SOLUTION and NAIL ⟶ COLORLESS SOLUTION and PINK COATING

as a result of the various tests of their model, can confidently be written as follows:

COPPER SULFATE SOLUTION and IRON ⟶ IRON SULFATE SOLUTION and COPPER

EXTENDED EXPERIENCE:

What do you predict will happen if a nail is allowed to interact with copper chloride?

Write the tentative word description for the interaction:

COPPER CHLORIDE AND IRON ⟶ COPPER AND ? ?

Will copper come out? If so, what will be left in solution? (See if they predict iron chloride.) The children can pursue this investigation duplicating what they did with copper sulfate: that is, first identify the characteristic crystals of copper chloride (elongate and bluish green). After the interaction with iron, the characteristic color disappears and the crystals can no longer be recovered. There is no more copper chloride in the solution. At the same time, a copper coating again appears on the nail. This interaction, as compared with that involving copper sulfate, is much more rapid. If steel wool is used, there is a very fast deposition of copper with a loss in blue color in the solution immediately surrounding the steel wool. (In fact, the copper chloride is so much more reactive than the copper sulfate that it will be displaced by ordinary aluminum foil. Aluminum is usually protected from interactions by a very adherent oxide coat. The copper chloride penetrates this coat. The aluminum then displaces it from solution, just as the iron did, forming free copper, and the aluminum replaces the copper in the solution, forming aluminum chloride.)

In a manner similar to the flame tests they just completed, the children may want to test the products of the interactions for the presence of copper units. The repeat of the interaction with this second copper salt serves to reinforce the concept of a replacement type of interaction and the idea of copper as a structural unit.

Activity 5 Putting the Blue Back In

In the earlier Activities in this sequence, the children were helped to develop a model of the interaction between a nail and copper sulfate built on the premise that copper was a unit of matter. Copper had been originally one of the component units of a dissolved salt. In the present Activity they will observe the synthesis of a blue copper salt--the units of copper now coming from a piece of copper metal. Here for the first time they cause units of copper to leave the free state and become associated with other units in the form of a salt.

The children will find that when a piece of copper is immersed in a colorless solution of silver nitrate, a blue solution forms. Furthermore, the appearance of the blue solution is accompanied by the appearance of a grey deposit. A model similar to the one used to explain the interaction of copper sulfate with the nail is developed to explain this "opposite" type of exchange. It is suggested that units of "free" copper exchange with units of silver in the dissolved silver nitrate to form blue copper nitrate and "free" silver. The transfer of units of copper into a salt is confirmed as children apply all their previous experiences on the properties of a dissolved copper salt--the interaction properties with an iron nail and the flame test. Discussion of their results emphasizes that not only can copper take part in such exchanges, but also iron and silver. As a result of these Activities, it is anticipated that the concept of a component unit of matter will have been established--whether or not the name "atom" is applied.

MATERIALS AND EQUIPMENT:

materials necessary to perform flame tests (Sterno, aluminum foil, ammonium chloride solution, paper clips)

1 polyfoam container, 3 qt (3 liter) capacity, unless warm tap water is available in the classroom

1 pint white vinegar, household variety

several squat containers for the chemicals other than the silver nitrate

overhead or microprojector (optional) with extra pieces of copper wire and silver nitrate solution

For each group of 4 or 5 children:

A small supply of the following: (about 1/8 teaspoon)

any sodium salt (sodium chloride, sodium thiosulfate, sodium sulfate, etc.)

silver nitrate crystals

copper (cupric) nitrate crystals (optional)

1 glass, "old-fashioned," 4- to 8-oz capacity, transparent plastic, or glass slide (optional)

2 (or more) test tubes, 100 mm x 13 mm, heat resistant

2 (or more) pieces of copper wire, at least 18 gauge, about 4-1/2 in. (12 cm) long

paper towels

1 cup, 1-oz (approximately 30-ml), waxed paper or plastic

1 jar, to serve as test tube rack

1 iron nail, 5 cm, common, with steel wool to clean its surface

PREPARATION FOR TEACHING:

Silver nitrate crystals can be obtained from a chemical supply house or in certain drugstores. Before the Activity begins, place about 1/8 teaspoon of silver nitrate in a test tube for each group of children. (A group size of 4 to 5 children has been suggested so as to reduce the requirement for the comparatively expensive silver nitrate. If economically feasible, you can consider decreasing the group size. If so, alter the other requirements accordingly.) The quantity is not critical--in the test tubes recommended, this would fill them to about 1/2 cm. It is advisable for you to prepare them for the children because if they should accidentally touch the silver nitrate, it will leave dark brown stains on their skin, even if they observe the precaution of washing it off immediately. These stains will eventually wear off. Place the test tube with the silver nitrate in the jar "test tube rack" for each group of children to help themselves. The other test tube can be filled with the same amount of the other salt by the children or by you. If the children are to take their own supply of the sodium salt, place it in containers with adequate dispensers as in the previous Activities.

The vinegar, diluted with an equal amount of water, will again be used as a dip for an iron nail. As before, each group of children will take their supply in a small cup.

Before beginning Section 3, place a supply of warm water (40°C to 50°C) in the polyfoam container. Place enough 30-ml cups next to it so that each group of children can take its own supply of water.

ALLOCATION OF TIME:

The children will need 1-1/2 to 2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Remind the children of the interaction they have just been investigating--where copper units from a salt were exchanged for iron units to produce "free" copper and an iron salt:	
COPPER SULFATE AND IRON →	COPPER AND IRON SULFATE
• What do you predict would happen if you could do the opposite--that is, take "free" copper from a wire or penny (or copper coating) and link it up with a partner in a salt?	
• How would you know if copper units leave the wire and form partners with other units to form a copper salt?	Look for the copper units in the liquid or in any new solid which might appear. The children will probably suggest that if it gave the characteristic green color in the flame test, this would tell them that the copper had changed places.
Suggest that the children investigate the interaction of copper with solutions of sodium chloride and silver nitrate. Write the names of the two substances on the chalkboard.	Any sodium salt (sulfate, thiosulfate, etc.) can be used in this activity.

TEACHING SEQUENCE	COMMENTARY
• What do you think are the units in sodium chloride?	Sodium units and chloride units.
• in silver nitrate?	From the name, silver units and nitrate units. In some ways it would be nice if a silver or other sulfate could be used in this Activity--in that case, copper sulfate, the salt with which they started, would be obtained. However, since silver is one of the few units which will exchange with copper and allow the copper to go into solution, we are forced to work with a soluble silver salt--silver nitrate. Silver sulfate is not very soluble.
• What could be used as a source of plain copper to replace the sodium or the silver in these materials?	If no one suggests trying a piece of copper metal (or the pieces of copper coating they saved from the earlier desplacement), remind them of how an iron nail was used to replace the copper in copper sulfate.
Distribute two pieces of copper wire to each group of children, along with a jar holding a test tube containing the silver nitrate. If the remaining test tubes do not already have the sodium salt in them, ask the children to help themselves, using the same techniques as when they obtained samples of the copper salts.	They will use copper wire, not pennies, for this part of the investigation because they want to insert the copper into the test tubes. Also, the copper will be used up excessively as it interacts with the silver nitrate--that would mean the destruction of the penny. Be sure the tube containing each salt is properly identified, as they look very similar.
Next, each group should get a supply of warm water in the small cup and add some water to each salt until the test tube is between 1/2 and 3/4 full.	It may take a little while for the salts to dissolve. The copper wire should be used as a stirrer. It is inadvisable for the children to invert or shake

TEACHING SEQUENCE	COMMENTARY
	the tubes to ensure dissolving. Definitely do not let them do this with silver nitrate since it might accidently touch their skin or interact with the cork.
As they add the water, have the children describe the properties of these salts.	They should include such properties as color (both are white), crystalline appearance, and the interaction property with water--both are soluble, forming colorless solutions in water.
If the copper wire is not shiny, the children should clean it with some steel wool. One end can be slightly bent so the wire can be used more efficiently as a stirrer. Then one wire should be inserted into each of the two solutions. After stirring a few times, have them observe each system carefully and report.	After dissolving, no change will be noticed in the sodium salt solution--an interaction with the copper does not appear to be taking place. Within a minute, however, distinct changes will be apparent in the tube containing the dissolved silver nitrate. This phenomenon will continue to generate excitement for at least the next half hour.
• What do you observe in the silver nitrate solution?	A greyish deposit starts to cover the copper wire. Within a few minutes, a blue color will appear in the solution around the wire.
While the interaction is proceeding, encourage them to develop hypotheses as to what might be happening. What might be producing the blue in the solution? What might the greyish material be?	All the while, the solution will be getting bluer. In 30 minutes to an hour, glistening silver crystals will form, sometimes in the form of a beautiful silver tree. As the interaction continues, some

TEACHING SEQUENCE	COMMENTARY
	children in the group should occasionally shake the tube so that the silver that is forming falls to the bottom, exposing more fresh copper.
With these questions in mind, have them set aside this test tube and the one containing the sodium solution until the next time.	
2. When the children have retrieved the test tubes, ask them what the systems look like now.	The test tube which contained the silver nitrate will be distinctly blue; the tube containing the sodium salt will still show no change.
• What do you think turned the liquid blue?	Some children may associate the blue color with copper salts merely on the basis of their experience with copper sulfate. (If they worked with copper chloride in the preceding Activity, they are even more likely to make this association.)
• What about the copper wire they started with? What does it look like?	In some cases it may have disappeared completely. In other cases it appears distinctly smaller. At the same time, there is now a considerable deposit of grey material in the test tube.
With their help construct a model of the interaction with silver nitrate. Start by writing the first half of the word equation for what happens in the solution:	

SILVER NITRATE AND COPPER ⟶ ? AND ?

Hopefully some children may exchange the copper and silver and suggest that copper nitrate is forming along with	If the children appear to have trouble suggesting the displacement description, repeat on the board what they found

TEACHING SEQUENCE	COMMENTARY
plain, "free" silver. Therefore on the right side of the word equation, SILVER should appear but not copper. The copper went into units of a salt which is blue.	when the iron interacted with the copper sulfate.
• Is the salt copper sulfate?	If some children say yes, ask them where the sulfate came from. Help those who seem unsure to see that the substance on the right is probably blue copper *nitrate*.
Now construct the complete model for the interaction:	

SILVER NITRATE AND COPPER ⟶ SILVER AND COPPER NITRATE

As you write the names, the interchange between the silver units and the copper units should be discussed--copper became a component unit of a soluble salt called copper nitrate and the silver was "freed" and appeared as the metal, silver.	Stress the similarity to the interaction between iron and copper salts. There, iron and copper units change places. Iron is "used up" and copper is "freed."
• How can we be sure that the copper units went into the blue substance formed in the water?	Some children may suggest evaporating the blue solution and looking at the crystals. If they do, they should realize that they would have to compare the crystals with those from *known* copper nitrate. If copper (cupric) nitrate crystals are available, they should be encouraged to make this comparison.
In the discussion the children should bring up both 1) the green flame test and 2) interaction with an iron nail. That is, *if* they obtain a positive flame test (green) from the blue solution, this would be evidence that copper units went into solution. And if a new iron nail can	Eliciting the second suggestion may require leading questions, such as: If this *is* a copper salt solution, will it interact with an iron nail as the copper sulfate did?

TEACHING SEQUENCE

displace copper out of the blue solution and re-forms metallic copper, this also would be evidence that copper was in the solution.

3. Before they start to test the solution, have the children filter it, because it may contain a considerable amount of silver. As they did in an earlier Activity, they can make a small filter with a square piece of paper towel formed into a cone. Filter into one of the 1-oz cups.

Once the blue solution is filtered, have each group divide it into two parts. One part can be placed in a small cup and one in a test tube. Two members of the group can use the first part for the flame test and the remaining children can use the other part of the solution, in the test tube, for the interaction with the nail.

If they are using a nail fresh out of the box, it should be thoroughly cleaned with steel wool first. (If the nail had previously been used in a copper solution, this will not be necessary.) Then, in the case of copper nitrate, it is essential that the nail be dipped in a small bit of dilute vinegar solution. After dipping, excess vinegar can be absorbed on a paper towel,

COMMENTARY

The purpose is to separate out the silver metal which has collected. This powdery precipitate should be saved. There may be a local market for recovered silver.

In flame testing the solution of the supposed copper nitrate, the children should follow the same procedures as in testing copper sulfate, including the dip in the ammonium chloride solution.

The flame will be a distinct green color, the same color they obtained from the copper wire.

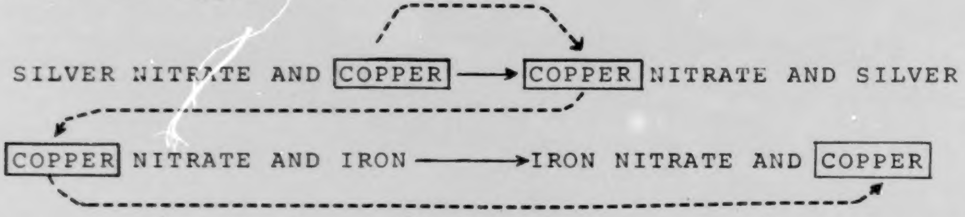
As mentioned in Activity 2, the vinegar dip is required for the interaction with iron by certain copper salts, some of

TEACHING SEQUENCE

as before, and the nail inserted into the test tube containing the blue solution.

The appearance of the copper on the nail, plus the green flame test, is positive evidence that the blue solution contains copper. By now the children should be convinced that copper units went from the wire into a soluble salt--as the word model indicated.

For the purpose of the discussion, it is important that children be helped to understand that in the first interaction, unit particles of copper went into solution and became associated with nitrate. In the second interaction, the same unit particles of copper appeared as a deposit on the nail as the iron interacted with the copper nitrate and freed the copper unit:


SILVER NITRATE AND COPPER → COPPER NITRATE AND SILVER
COPPER NITRATE AND IRON → IRON NITRATE AND COPPER

COMMENTARY

which, depending on their concentration, need a slightly acidic environment. Without the vinegar the copper may not "plate out."

Immediately on immersing the blue solution, copper will start to appear on the nail. If the solution is dilute enough, and if the nail is left in, copper will continue to form until all the blue disappears. (Here again, however, if left partially exposed to the air, some rust may also start to appear.) As the nail interacts with the blue solution, again a replacement of units takes place: the copper units come out and iron takes its place. The color of the solution gradually becomes green as iron nitrate is formed at the expense of the copper nitrate. See if the children realize what is going on in this second interaction before any discussion of it.

TEACHING SEQUENCE

Bring the discussion together to include both interactions and to emphasize the unit particle idea: both the copper and its salts contain units of copper; the silver and its salts contain silver units; the iron and its salts contain iron units.

The concluding discussion should attempt to generalize about these units, which appear to be parts of larger molecules but are also able to appear alone. These Activities focused on the copper unit and followed it from a component in a salt, to the free metal, back into a salt, and finally into the free metal again. Similarly, iron units were free in the nail but could become part of a soluble salt and they saw units of silver come out of a colorless solution as copper units went in to take their place.

COMMENTARY

Use of the term "models" of these two interactions during the discussion will help to emphasize the integrity of each particle unit and its ability to be "free" or "alone," as a metal, or a partner of other unit particles in other molecules. They will also help to emphasize the "movement of units of copper from the metal into a salt and out again.

The children should not be misled into thinking that any unit can be so easily freed. Certain interactions can take place readily, others cannot. Although copper could readily be freed from a blue salt by iron (and some other metals), it would be more difficult to free the iron, say, from iron sulfate. Similarly, there are only a few substances which will spontaneously exchange with the metal copper and put it back into a salt. One of those substances is silver.

EXTENDED EXPERIENCE:

An interesting variation on the theme developed in this Activity can be carried out using copper and vinegar: If the children put a penny (polished with steel wool, if necessary) into a small jar, cover it with white vinegar (undiluted), and set it aside for a day or so, they will observe the same kind of interaction as with the copper wire and silver nitrate. (The products, however, will be different.) A blue solution will appear around the penny. Again, tests of the solution will reveal the presence of copper. It produces a distinct green flame test and, if allowed to evaporate, the resulting deep blue crystals will also give the green flame.

In order for the children to understand what is happening in this reaction, tell them that vinegar is a solution of acetic acid. Acid molecules all contain hydrogen and thus acetic acid could be called hydrogen acetate. What, then, is the blue substance in the solution? The following word-equation can describe the interaction:

$$\text{COPPER AND HYDROGEN ACETATE} \longrightarrow \text{COPPER ACETATE AND } \overset{?}{\text{HYDROGEN}}$$

The blue substance is another copper salt, copper acetate, As they view this interchange of copper units, help them to see its similarity to the other interchanges in which copper moved into a molecule to form a salt or moved out of a molecule to form the metal.

Minisequence IV
A Tendency To Spread Out

It is in this Minisequence that COPES develops the culminating ideas in the conceptual scheme, Degradation of Energy. In Grade 5, Minisequence IV, reference was made to the observation that in any practical system, while the total amount of energy remains constant, there is a tendency for it to be converted to heat. In general, this is a less useful form of energy than mechanical energy, or electrical energy, etc., because it cannot be converted efficiently to these forms. That is, while mechanical energy or electrical energy--or any other conventional form of energy--can be completely converted to heat energy, the reverse turns out to be impossible. For example, it can be shown that in order to have heat energy do useful work, as it does in a steam or gasoline engine, there must be a temperature difference between the inlet and outlet regions of the system. The greater this temperature difference, the more efficient is the process of conversion, although for all practical purposes the conversion does not even approach being 100% efficient.

Thus, since all practical systems convert some energy to heat (because of friction)--and this heat energy, in turn, cannot be fully converted back to other forms--it follows that the total energy of the Universe is gradually being transformed to heat energy. This is known as "The Degradation of Energy," implying only that the energy is being degraded to a less useful form.

We know that the direction of heat energy transfer is from regions of higher temperature to regions of lower temperature. If we think of temperature in terms of the kinetic energy of the molecules (or structural units) of the substance, we can understand why heat transfer occurs in this direction. The "high temperature" molecules collide with their immediate neighbors, which in turn collide with their neighbors, and in this way "transmit" the energy of motion (kinetic energy) from the high temperature region to the low. The reverse is impossible simply because the molecules in the low temperature region do not have enough energy to add to the already higher energies of their neighbors. The illogic of the reverse situation should also be apparent from the fact that if heat transfer could occur spontaneously from regions of lower temperature to higher temperatures, the low temperature regions would become colder while the higher temperature regions became hotter--which, of course, is contrary to experience. This is what happens in a refrigerator only because outside work is done on the system by way of an electric motor.

It is convenient to think of higher temperature regions as having higher "concentrations" of heat energy--that is, higher concentrations of more energetic molecules. Then, just as higher concentrations of molecules tend to equalize by spreading out (as in a drop of food coloring added to water), heat energy tends to spread out from regions of higher temperature (higher concentration) to regions of lower temperature (lower concentration). The reverse does not occur. One would not expect to find a drop of food coloring become more concentrated when added to a liquid such as water. This tendency for matter to spread out and thereby equalize concentrations is analogous to the spreading out of heat energy, and is therefore useful as a means of conveying this concept to children.

The degradation of energy is a very important conceptual idea in science because it predicts what must happen in any real situation, as well as the ultimate fate of the Universe. If the energy in the Universe is being transformed to heat, and the heat energy distributes itself uniformly throughout the Universe, it follows that the Universe, as we know it, must eventually run down.

The first Activity is a review of the conept of heat energy as applied to mixtures of water samples, as investigated by the children in Grade 4, Minisequence II. They review the definition of the heat energy unit (h.e.u.), and through quantitative observations conclude not only that heat energy is conserved in water mixes, but that it "spreads out" from higher temperature regions to lower. In the next Activity the children continue their study of the effect of the "spreading out" of heat energy. For example, they find that, given two samples of water at different temperatures, the one at the lower temperature, while containing more heat energy than the higher temperature sample (because of its greater volume), is unable to melt a certain solid while the other can. In other words, the energy in the lower temperature sample is degraded--in the sense that it is unable to perform the work required to melt the solid (break the bonds).

The third Activity extends this experience to the case where water samples are not physically mixed with one another, but are simply brought into thermal contact. Here the children find, as expected, that the direction of heat transfer is from the higher temperature sample to the lower. The same "spreading out" from higher to lower concentrations is observed in the next Activity, but this time in connection with the spread of food color (molecules) rather than heat energy.

A model in the form of a game of chance is introduced in Activity 5 to account for this "spreading out" or transfer of colored molecules form regions of higher concentration to regions of lower concentration. Activity 6 continues with an experimental model that is analogous to that of the previous

Activity, but one that actually uses colored liquids to depict the spreading out of color in stepwise fashion (a gradient or gradation of color is produced)--and ultimate uniformity of color throughout the model. However, in this case, instead of restricting the transfer only between two samples, the transfer takes place between adjacent cups in a series. In this way, the system within which the transfer is taking place is open ended. The intent is to lead into the final Activity of the sequence where heat energy is added at one end and is removed by the surrounding air continuously. It too is open ended.

This final Activity has the children investigate the transfer of heat through a solid (along a nail). Here they find the same sort of spreading from the higher temperature end of the nail to the lower, with the same kind of gradient formed as in the earlier Activities dealing with color gradients, but the gradient is that of temperature. Thus they conclude that whether dealing with matter or energy, there is a tendency toward equalization or equilibrium--a spreading out from higher concentrations to lower.

The following concepts are developed in Minisequence IV:

1. When two samples of a liquid at different temperatures are placed in thermal contact, where heat energy transfer can take place,

    a. the transfer will be from the sample at the higher temperature to that at the lower temperature;

    b. the total heat energy in all parts of the system remains a constant. Heat energy is conserved.

2. Although heat energy is conserved on mixing samples of water having different temperatures, the available heat energy, being at a lower temperature, may no longer be able to perform certain work--such as breaking bonds within certain solid substances. That is, the heat energy has been degraded.

3. There is a natural tendency for molecules to spread out into whatever space is available to them.

4. Molecules tend to move from regions of higher concentration to regions of lower concentration, just as in the transfer of heat energy.

5. As the molecules disperse, (spread out over a period of time), there develops a smooth gradation (gradient) in concentration from the higher to the lower concentration regions.

6. Systems, if left to themselves, tend naturally towards

equilibrium, e.g., equal concentrations of molecules and equal temperatures.

7. The spreading out into regions of lower concentration and the attainment of the state of equilibrium should be thought of as a "net" or average effect. At the molecular level, some molecules may be moving in the reverse direction--into regions of higher concentration.

Activity 1 The h.e.u. Revisited

The children will begin this series of Activities, which is devoted to the tendency of both matter and energy to spread out or become less concentrated, by considering heat energy. In order to focus on the spreading out of heat energy, the quantitative concept of the heat energy unit (h.e.u.) is reintroduced in this first Activity. As in Grade 4 of COPES, the children will discover that the heat energy in a water sample depends on the volume of water as well as on its temperature. They will observe that of two different-sized samples of water at the same temperature, the larger sample will melt more ice--a measure of its heat energy content. The amount of heat energy contained in each sample of water, expressed in heat energy units, is a product of its volume and its temperature. Initially the product is arrived at by a graphical area count as they prepare bar graphs to represent the two water samples. The height of each bar represents the temperature; the width, or number of columns, represents the volume. Inspection of the number of h.e.u. squares enclosed in each bar helps the children to explain why the larger sample of water was able to do more work in melting the ice. Consideration of the number of h.e.u. in the water mix formed by combining the two samples then provides them with a review of the concept that heat energy in the mix is the same as the sum of the heat energies of the two samples making it up.

MATERIALS AND EQUIPMENT:

6	polyfoam containers, minimum size 3-qt (3-liter), with lids
16	cups, 1-oz (approximately 30-ml), plastic or waxed paper
2	plastic bags, approximately 11-in. by 13-in.
75	ice cubes (see Preparation for Teaching)
1	roll or stack of paper towels (at least 60)

In addition, for each pair of children, you will need:

2	polyfoam cups, 8-oz (approximately 240-ml)
2	stirrers, wooden or plastic for beverages, popsicle sticks, etc.

1 thermometer, -20°C to +50°C, plastic backed, e.g., Macalaster No. 2662

2 pencils and/or felt-tip pens

2 pieces of graph paper, 4 squares per inch (or 2 per cm)

PREPARATION FOR TEACHING:

If the comparison of the amount of ice melted by two systems is to be meaningful, the same size ice cubes must be used. Also, for the conditions set up in this Activity an ice cube which yields at least 1-oz of water is needed. If the ice is in cubes, then the minimum size would be 1-1/4 in. on a side. Ice trays with molded-in sections are ideal for making such uniform cubes provided they are filled to the same height so that each section yields a cube of the specified dimensions. They can be filled to the same height by placing into each section a unit measure (1-oz) of water. An even more convenient method of obtaining uniform cubes is to freeze water directly in a sufficient number of the unit-measure cups. Then each cup will yield the same size and shape "cube," and comparisons of the ice remaining after experimenting can be easily made.

When you are ready to begin, put 30 or more ice cubes into the two plastic bags, and put the bags of ice into two of the polyfoam containers. The remaining four insulated containers should be 2/3 filled with water at about 20°C. Additional ice cubes will be needed for Section 3.

ALLOCATION OF TIME:

About 1-1/2 to 2 hours will be needed to complete this Activity. More time may be necessary if the children have not had the COPES Water Mix Experiences described in Minisequence II os the Grade 4 Teacher's Guide or in the American Science and Engineering (AS&E) booklet, Water-Mix Experiments.

TEACHING SEQUENCE	COMMENTARY
1. Show the children one of the ice cubes you have prepared and ask them what is necessary for it to melt.	The children will undoubtedly respond that heat energy is required to break the bonds holding the molecules in the solid. (See the review of this concept in Activity 1 of Minisequence II.)

TEACHING SEQUENCE	COMMENTARY
• Which do you think would melt more ice, water at a low temperature or the same amount of water at a higher temperature?	Children who have had the Water Mix experiences will know that the higher temperature water will melt more ice. If the children have not had these experiences, let them try it out, using, say, 2 measures of the water at 20°C and 2 measures of 40°C water. One measure of water is the amount that will fill a 1-oz (30-ml) cup to the brim.
• Suppose the two samples of water were at the same temperature but one sample contained twice as much water as the other. Do you think they would melt the same or different amounts of ice?	Even children who have had the Water Mix experiences may be unsure of what would happen in this situation.
Put one measure of water from one of the water containers into one foam cup and mark it with a "1." Put two measures of water from the same container into a second foam cup and mark it with a "2."	
• What is the volume of water in each sample?	The samples contain different volumes: one has 2 measures, the other 1.
• What can you predict about the temperature of each?	Since each sample came from the same reservoir, they should be at the same temperature.
Now have the child take one of the thermometers and measure the temperature in each cup.	Both samples should be at 20°C.
• Do you think the samples differ in the amount of heat energy they contain?	Encourage the children to express their opinions.
• How could you find out?	Hopefully, some children will relate the amount of heat energy with the amount of ice which could be melted. Thus

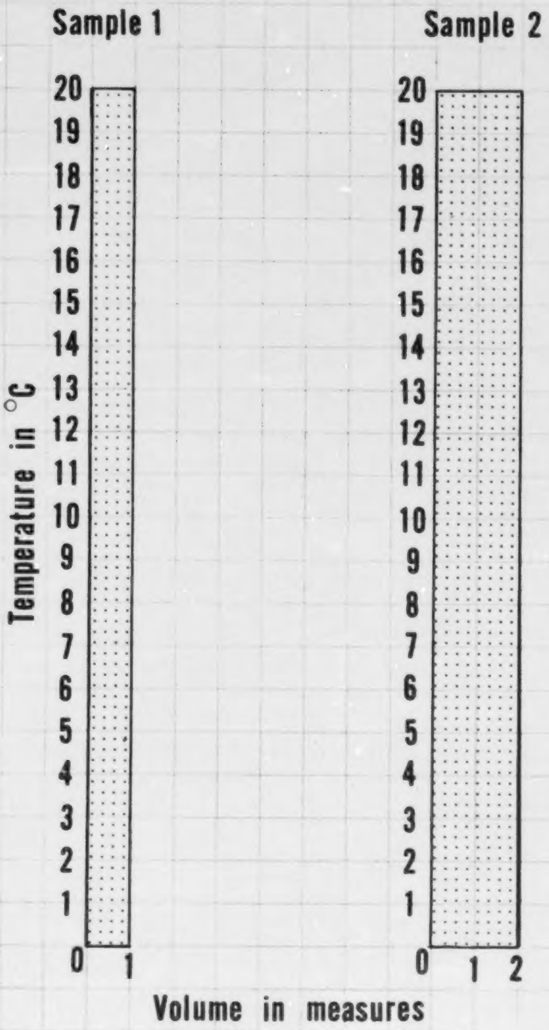
TEACHING SEQUENCE	COMMENTARY
	they could find out by seeing which sample will melt more of the solid ice.
The children can work in teams of two. Give each team two polyfoam cups, a thermometer, two stirrers, and two paper towels. Each team should obtain two samples of water, one sample with 1 measure and the other with 2 measures.	
After the children return to their places, they should place the cups on one of the paper towels.	They may find it helpful to mark their sample cups with a 1 and a 2. They could also put corresponding marks on the towel in front of each sample.
Using the same thermometer, have the teams check the temperature of each sample being investigated to be sure they are the same.	The temperature should be the same. Because of slight variations in response between thermometers, each team should use the same thermometer to check both samples. If there are differences of more than one or two degrees in reading temperatures, the following might be the causes: a. Failure to read the thermometer at eye level. b. Touching the bulb of the thermometer with one's finger. c. Slippage of the stem along the plastic backing. This can be overcome by checking against other thermometers for the "true" reading and then, with a piece of cellophane or masking tape at the top resecuring the stem to the plastic. It is important that this slippage not occur. Otherwise, the children will obtain erroneous temperature readings.

TEACHING SEQUENCE	COMMENTARY
Next, the children should use the other paper towel to obtain two ice cubes. At a time signal, each child in the team should put one of the cubes into one of the water samples and stir gently with a stirrer for 3 minutes.	The stirring should be continuous.
When the 3 minutes is up, the children should remove the ice cubes and place them on the paper towel in front of their respective cups. Ask them to mark the size of each cube on the paper towel.	There will be less ice in the cube that was removed from the sample which contained 2 measures of water. The paper towel record should be saved for reference in Section 3.
• Which water sample melted more ice?	The larger sample melted more ice.
• Which water sample appears to have contained more heat energy?	Since the larger sample melted more ice, it must have contained more heat energy.
• What two properties of a water sample determine how much heat energy it contains?	Both temperature and volume determine the amount of heat energy in a sample.
2. At this point, distribute the sheets of graph paper--one to each child. They should also have pencils. Suggest that they use the graph paper to represent the heat energy in the one measure of water at 20°C.	
This can be done by letting the height of a space represent 1°C and the width of the space represent 1 measure. Since the water in their sample was at 20°C, they could count up 20 spaces and make a	You may find it helpful to use

TEACHING SEQUENCE	COMMENTARY
mark across the top. They should do this, starting a few spaces from the bottom of the paper. By retracing the lines around a single column of 20 squares with a pencil, they will then have represented the sample of water. They can use felt-tip pens to color in lightly the squares in the column. Each square can be thought of as a *heat energy unit* (h.e.u.).	a grid on the chalkboard or overhead projector as you discuss the way of representing this with the children. If felt-tip pens are not available for shading in the heat energy units on the graph, their pencils can be used to crosshatch the area. Crayons are not recommended because they make heavy marks that obscure the grid, making it difficult to count the h.e.u. squares.
• How many heat energy units are shown in this representation?	The heat energy unit is being defined here as 1 square (1°C) high and (1 measure) wide, expressing the fact that the amount of heat energy is determined by both the temperature and the volume of a sample. Thus, this representation of 1 measure of water at 20°C shows 20 h.e.u. squares. The h.e.u. was introduced in Activity 2 of Minisequence II in Grade 4. If you feel that the children need a more extensive introduction to it here, refer to that Activity.
Next, ask the children how they could represent their other sample of water--the one containing 2 measures of water at 20°C.	
• How high should the representation be?	Since the temperature of this sample is also 20°C, the height should be the same as before.
• How wide should it be?	Since the width represents the volume, they must mark off two columns of squares to represent the 2 measures of water

TEACHING SEQUENCE	COMMENTARY
	in the second sample.
Have the children outline an area to represent the 2-measure sample of 20°C water. It should be 2 columns wide and 20 squares high.	Be sure the children select two adjacent columns, as shown on page 256.
Then, as before, ask them to use their felt markers or pencils to lightly shade in the representations.	
Next, review with the children what the height and width of the graphs represent. The axis running vertically represents the temperature in degrees Celsius and the horizontal axis represents the volume of water. They should label the axes accordingly.	
• How many heat energy units does the graph of the 2-measure sample show?	Again, they should count the shaded squares. They will find they have 40 of them. Note that the children are really calculating the product of volume times temperature by counting the enclosed squares. Seeing the area of the squares on a graph permits concrete visualization of the value of the product, V x T. However, at this level, many children will be ready to substitute arithmetic multiplication for the graphical calculation.
• In what other way could you have found the number of heat energy units in this (and the other) sample?	The children will probably realize that they could multiply 20°C by 2 measures and arrive at 40 h.e.u.
On the chalkboard or overhead projector, write down the temperature and volume of the sample. Indicate the number of h.e.u. underneath:	

TEACHING SEQUENCE	COMMENTARY
Temp. 20°C Volume 2 measures h.e.u. 40 In this fashion the children can record the temperature and volume, along with the number of h.e.u., for both samples under their respective graphs on the graph paper.	As they consider this calculation, you might ask the children if they could find the temperature of a sample, knowing its volume and the number of h.e.u. it contained. See if they understand that dividing the h.e.u. by the number of measures would yield the temperature--e.g., 40 ÷ 2 = 20°C.
• How does the number of h.e.u. in the two measures of water compare with the number of h.e.u. in the single measure of water at 20°C?	By comparing the heat energy units, the children should see that when the amount of water was doubled, the number of heat energy units was doubled. There was more heat energy in the larger sample, even though they were both at the same temperature.
• How does this help explain why the larger sample was able to melt more ice?	Heat energy is necessary to do the work of breaking the bonds holding the water molecules together in the ice. Since there was more heat energy in the larger sample than in the smaller sample, as expressed in h.e.u., the larger sample was able to melt more of the solid.
3. Now return to the experimental setup: Again put one measure of water at 20°C into one foam cup and 2 measures into another. Then ask the children what they think would happen to a cube of ice placed in a mixture of the two samples. Will more, less, or the same amount of ice be melted by each sample separately?	Refill the containers with 20°C water before beginning this Section. You will also need more ice cubes. Reactions usually vary here. Some children predict right away that more ice will be melted because of the increased volume of water in the mix. Some even suggest that three times as much will be melted as was melted by sample 1. Children who have gone through Activities 4 and 5 of The Water



Temp. ______
Volume ______
h.e.u. ______

Temp. ______
Volume ______
h.e.u. ______

TEACHING SEQUENCE	COMMENTARY
	Mix are, of course, more likely to respond in this way.
• What would be the temperature of such a water mix?	The children may or may not say that the temperature will remain unchanged.
• What would be its volume?	There should be general agreement at this level, that there will be 3 measures of water in the mix. Volumes of water are always conserved when added together.
Ask the children to obtain the two samples of water as before. After recording their temperatures and volumes, have them pour one sample into the other to make the mix. The temperature and volume of the mix should also be recorded. Then an ice cube can be put into the cup and the contents stirred for three minutes. After the cube is removed, its size can be marked on the paper towel. Comparison with the sizes recorded on the other paper towel earlier can then be made.	Be sure that this information is recorded *before* the ice cube is put in! It may be clear, even without this comparison, that more ice was melted by the mixture of water than by either of the two samples.
• What was the temperature and volume of the mix before the ice cube was put in?	The temperature of the 3 measures of water was 20°C--the same as that of the samples.
• How many h.e.u. did the mix contain?	Knowing the temperature and volume, the product can be calculated arithmetically: 20 x 3 = 60 h.e.u. However, ask the children to do a graphical calculation as well. This way they can see that the area of the graph is the same as that of the other two areas (of the graphs for the separate samples) combined.
• How does the number of h.e.u. in the mix compare	The children should realize that the number of h.e.u. in

TEACHING SEQUENCE	COMMENTARY
with the number of h.e.u. in the samples?	the mix is the sum of the h.e.u. in the two samples: 60 = 20 + 40. That is, all the heat energy units of the original samples were still present in the mix. In other words, heat energy is conserved.
Before going on to Activity 2, the children should have arrived at the understanding that the amount of heat energy in the water mix is the same as the total of heat energies in the two samples (provided that no heat energy is lost to the environment in the process). A review of this concept is important to the subsequent development of ideas in this sequence.	

Activity 2 Unavailable for Work

In this Activity the children will continue to focus on the heat energy contained in samples of water and on the work that this heat energy can do in breaking the bonds in solids. But this time it is a solid other than ice. They will discover that a sample of water at 50°C can melt some salol, whereas one at a lower temperature (25°C) cannot. When these two samples are combined, their prior experience tells them that the mix now possesses the total h.e.u. of both the original 25°C and 50°C water: heat energy is additive and thus conserved on mixing. But the mix cannot do the job of melting the salol! The temperature is too low. The total heat energy is present in the mix but is spread out or dispersed as a result of mixing higher temperature water with lower temperature water--resulting in a temperature inbetween the two. The inbetween temperature is too low to do what the 50°C water could do, even though the mix contains much more heat energy than the higher temperature sample. Although conserved, the energy is unavailable--in other words, it is "degraded."

MATERIALS AND EQUIPMENT:

4 polyfoam containers, 3 qt (3 liter) capacity, with lids

1 hot plate

1 thermometer, registering temperatures above 60°C

1 large saucepan to heat water

a supply of salol (phenyl salicylate) about 1 cup

several narrow wooden dispensers, such as popsicle sticks, beverage stirrers, etc.

2 or more squat containers to serve as supply stations for the salol

For each team of two children:

3 polyfoam cups, 8-oz capacity

2 aluminum foil muffin cup liners or 3 in. by 3 in. (7.5 cm by 7.5 cm) pieces of aluminum foil

graph paper, 4 sq/in. (or 2/cm)

scrap paper

PREPARATION FOR TEACHING:

Fill two of the polyfoam containers 2/3 full with water at room temperature (20°C-25°C) and label them with the letter A. Fill the other two with hot water (50°C-55°C). Label these with the letter B. Lids should be placed on all the containers to prevent the loss of heat energy, particularly from the high temperature water, to the surroundings. For this purpose you can keep a large saucepan or tea kettle of water simmering on the hot plate and add some as necessary; or, if hot tap water is readily available, you can use that when needed. Keep a check on the temperature of the hot water by means of thermometers registering temperatures above 60°C.

Put out the supply of salol in two containers. Place the dispensers alongside. As in Minisequence II, Activity 1, the salol will be placed by the children on aluminum dishes which can be formed from squares of foil as described there. (See page 109.) Again, if the aluminum foil muffin-cup liners are available, they make excellent dishes.

ALLOCATION OF TIME:

The children will need 1 to 1-1/2 hours for this Activity.

TEACHING SEQUENCE

1. Let the children watch as you pour two unit measures of cool water into a polyfoam cup. Put a thermometer into this water sample and stir it a little. Have one or two children read and report the temperature. Write this and the volume of the sample on the chalkboard:

Sample A

Temperature 20°C
Volume 2 measures

Then put two unit measures of hot water into another, double polyfoam cup. Put a

COMMENTARY

Because the temperature of the hot sample is so high, using a double foam cup--that is, one

TEACHING SEQUENCE

thermometer into this water sample. Stir it a bit. Then have one or two children read and report this temperature. Record it and the volume on the chalkboard:

Sample B

Temperature 50°C
Volume 2 measures

Next mix the two water samples together, add a thermometer, stir and ask one or two children to read the temperature and write it down but not to report it to the class yet.

- What do you predict will be the temperature of the mix?

The exact method the children use to predict the temperature is not important. After they have made their predictions, the one or two who read it can report the measured final temperature. After comparing it with prediction, the children should calculate the actual number of h.e.u. in the mixture to see that it is about equal to the total number of h.e.u. in both of the initial samples.

COMMENTARY

nested inside another--will prevent too great a loss of h.e.u. The loss would show up as a temperature lower than that predicted by calculation.

In order to limit the loss of heat energy to the surroundings, it is advised that the cold water sample be poured into the hot one.

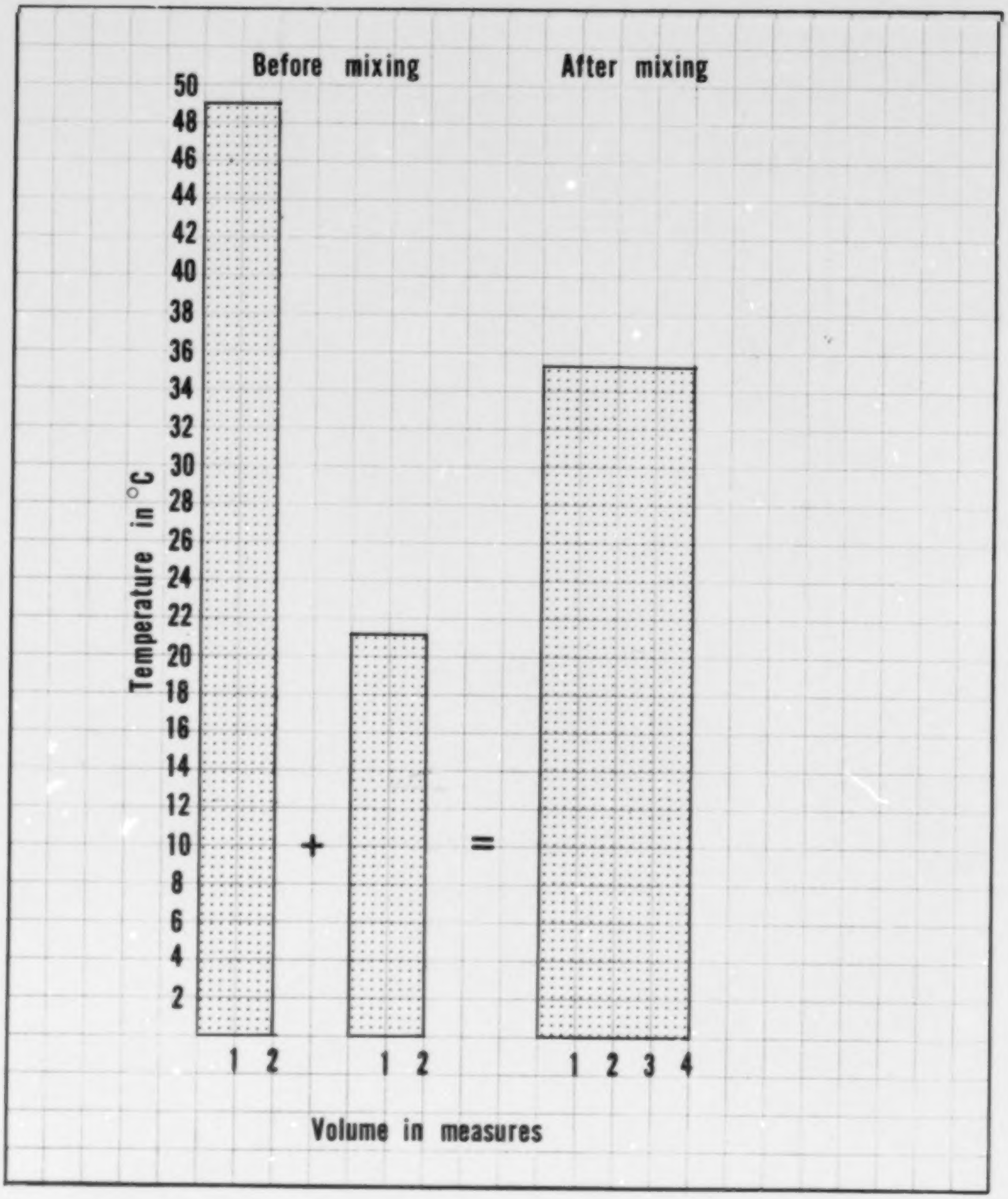
The children have learned that the total number of heat energy units is unchanged by such a mixing. This provides a way of predicting the final temperatures of such mixes. In the example given, the number of h.e.u. in sample A is 2 x 20 = 40; the number in sample B is 2 x 50 = 100. Therefore, the number of h.e.u. in the mix should be about 140. The volume of the mix will be 4 unit measures. Therefore, the predicted temperature of the mix will be such that the number of degrees multiplied by 4 equals about 140. By the graphical method, this would mean finding the height of a bar graph 4 units wide containing 140 square units. The arithmetic calculation would be 140 ÷ 4 = 35°C.

The predicted and measured temperatures of the mix may not agree exactly because of some loss of heat energy to the surroundings. However, they should be close.

TEACHING SEQUENCE	COMMENTARY
	Again, if the children need more experience in predicting the temperature of mixes from samples at two different temperatures, refer to the AS&E Water-Mix Experiments booklet or Minisequence II of Grade 4.
2. Now show the children the supplies of salol and suggest that they find out which of the two samples of water will melt more of the solid.	Be sure the temperature of the water in the containers is unchanged. The children will be familiar with salol, and with the aluminum foil dishes used for melting, as a result of their work in Minisequence II.
The children can again work in teams of two. One child can go to the water supplies and put 2 measures of the cold water in one polyfoam cup, labeled A; then he or she should put 2 measures of hot water in a double polyfoam cup, labeled B. The other child should go to one of the supply stations for the salol and place several unit measures of the crystals in each of two foil dishes.	As in Minisequence I, a unit measure is that amount of solid which can be picked up on the end of the wooden stick, which is marked off at a distance of 1 cm.
After checking the temperature of each sample, they should place each of the dishes with the salol in a cup so that it rests on the water.	Be sure the dish is of such a size that it can go into the cup as far as the surface of the water. It is essential that the aluminum be directly in contact with the water--not the air above it.
Ask them to observe closely any changes which occur.	The children will observe that the phenyl salicylate in the dishes placed on water from

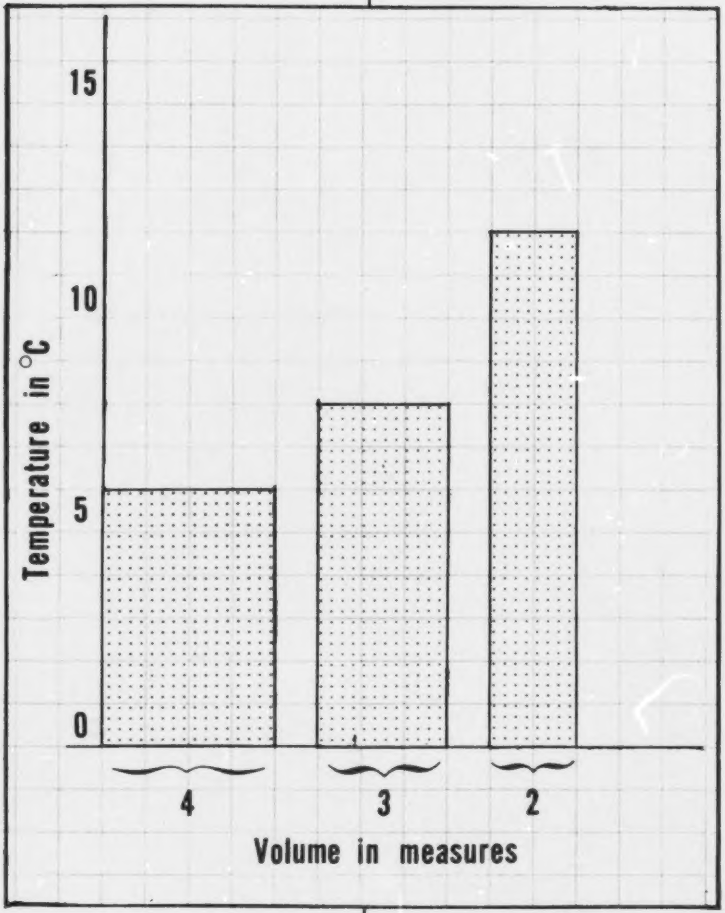
TEACHING SEQUENCE	COMMENTARY
	the supplies labeled B soon melts (the melting temperature of salol is 43°C); no change will be observed in the dish placed on water from supplies labeled A.
• Why do you think the salol melted when placed on Sample B but not on Sample A?	According to the children's earlier calculations, sample B contained 100 h.e.u. while sample A contained only 40 h.e.u. They may reply that the heat energy in sample B was sufficient to break the bonds holding the molecules of salol in the rigid crystal structure, while that in sample A was not. (This is not the reason, as they will find later, but accept this response for the time being.)
• How many h.e.u. will be in the mixture when the water in both cups is combined?	There will be 140 h.e.u. in the mix.
Now have the children predict what they think will be observed if the two samples are combined and the dish of unmelted salol crystals is placed on the mix.	Since the combined sample will have more heat energy even than the sample that did melt the salol, most children probably will predict that the crystals will melt.
3. The children should then carry out the experiment to check on their predictions.	Again, check the temperature of the water in the containers to be sure it is unchanged. No melting will be observed!
Some children will suspect that the water in their cup has cooled, (lost heat energy to the surroundings) and that this explains the failure of the crystals to melt. They can repeat with fresh samples of water from the supplies, or check the temperature of their water to see if it agrees with their predicted temperature.	

TEACHING SEQUENCE	COMMENTARY
When all attempts fail to melt the crystals with the combined water samples, ask for an explanation:	
• Doesn't a combined sample have more heat energy units than either of the original samples? Then why can't it melt the crystals when one of the smaller samples can?	Yes. The heat energy is "spread out" too much in the combined sample. Some children may also suggest that the temperature is not high enough.
Ask the children to prepare "before" and "after" graphs to show how the heat energy was spread out by the mixing of their two samples. For this purpose give each a sheet of graph paper on which to mark temperatures, volumes and squares representing the h.e.u. An example is shown on page 265.	Note that if the children are using graph paper with 4 sq/in., it will be necessary to let the height of each square represent 2°C if the temperature of the hotter sample is to be accommodated even lengthwise on the paper (unless they want to paste two sheets of paper together).
	When the children give either "low temperature" or "spread out heat energy" as an explanation, you can show them that these are two ways of saying the same thing. When a given amount of heat energy is spread out through a larger volume of water, the temperature must be lower than if the same amount of heat energy were concentrated in a smaller amount of water. You can show this graphically by putting 24 h.e.u. in 4, 3, and 2 measures of water. This will produce graphs filled up to the 6°C, 8°C, and 12°C lines respectively, as shown in the illustration on page 266.


Before mixing
After mixing
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Temperature in °C
+
=
1 2
1 2
1 2 3 4
Volume in measures

TEACHING SEQUENCE

COMMENTARY



In the mixing example shown on page 265, the temperature of the hotter sample was 49°C when measured and the colder sample was 21°C. When the heat energy was spread out in the mix, its temperature was 35°C. From the graphs, the children may notice that, in effect, this could be achieved by transferring h.e.u. from the higher column to the lower one. In other words, heat energy went from the

TEACHING SEQUENCE	COMMENTARY
	higher temperature sample to the lower. If they do, this will provide a nice transition to the next Activity. There the children will observe the transfer of heat energy from two separated parts of a system and rediscover that heat energy is transferred only from higher temperatures to lower temperatures, even if there is more total heat energy at the lower temperature. The children's before-and-after graphs should be saved for reference in Activity 3.
• Was there any loss of h.e.u. in mixing?	No. Heat energy was conserved, as expected.
• What did the system lose?	It lost the ability to melt the solid salol when the heat energy was spread out. The heat energy was there, but unavailable for work because of the temperature.

Activity 3 From Higher Temperatures to Lower Temperatures

In the present Activity, the children will again observe the spreading out of heat energy, but in this instance there is no actual mixing of the samples of water. Instead, the samples are physically isolated from each other but in thermal contact. Heat energy can pass through the walls of the container separating the two. By calculating the h.e.u. before and after the samples are in contact, children will realize that again heat energy is conserved. They will also observe that the heat energy is transferred only from the sample at the higher temperature to the one at the lower temperature, no matter what the original heat energy content of the samples. Even if the lower temperature sample has more h.e.u. in it, it will still gain h.e.u. if it is in contact with a sample which is hotter. Children will follow the changes in temperature with time as the two samples are in contact and represent the changes on coordinate graphs. The graphs in all instances portray the direction of heat energy transfer--from the higher to the lower temperature sample. This observation, which was introduced in Grade 4, Minisequence III is one of the cornerstones of the conceptual scheme the Degradation of Energy. In the following Activity the children will observe a very similar phenomenon with the transfer of colored molecules through a barrier membrane.

MATERIALS AND EQUIPMENT:

1 clock or timer with sweep second hand

6 polyfoam containers, 3-qt (3-liter) capacity

For each pair of children:

1 polyfoam cup, 8-oz (240-ml)

1 cup, plastic, about 5-oz (150-ml)

2 colored pencils or crayons, preferably of different colors, such as red and blue

2 thermometers, -20°C to +50°C

graphs from previous Activity

1 Worksheet IV-1

2 pieces of graph paper, 4 sq/in. (or 2/cm)

PREPARATION FOR TEACHING:

Half fill 2 polyfoam containers with water at 30°C to 36°C; half fill the rest of the containers with water at 15°C to 18°C. (The hotter water should have a temperature about twice that of the colder.) Only the cooler water will be needed for Section 1.

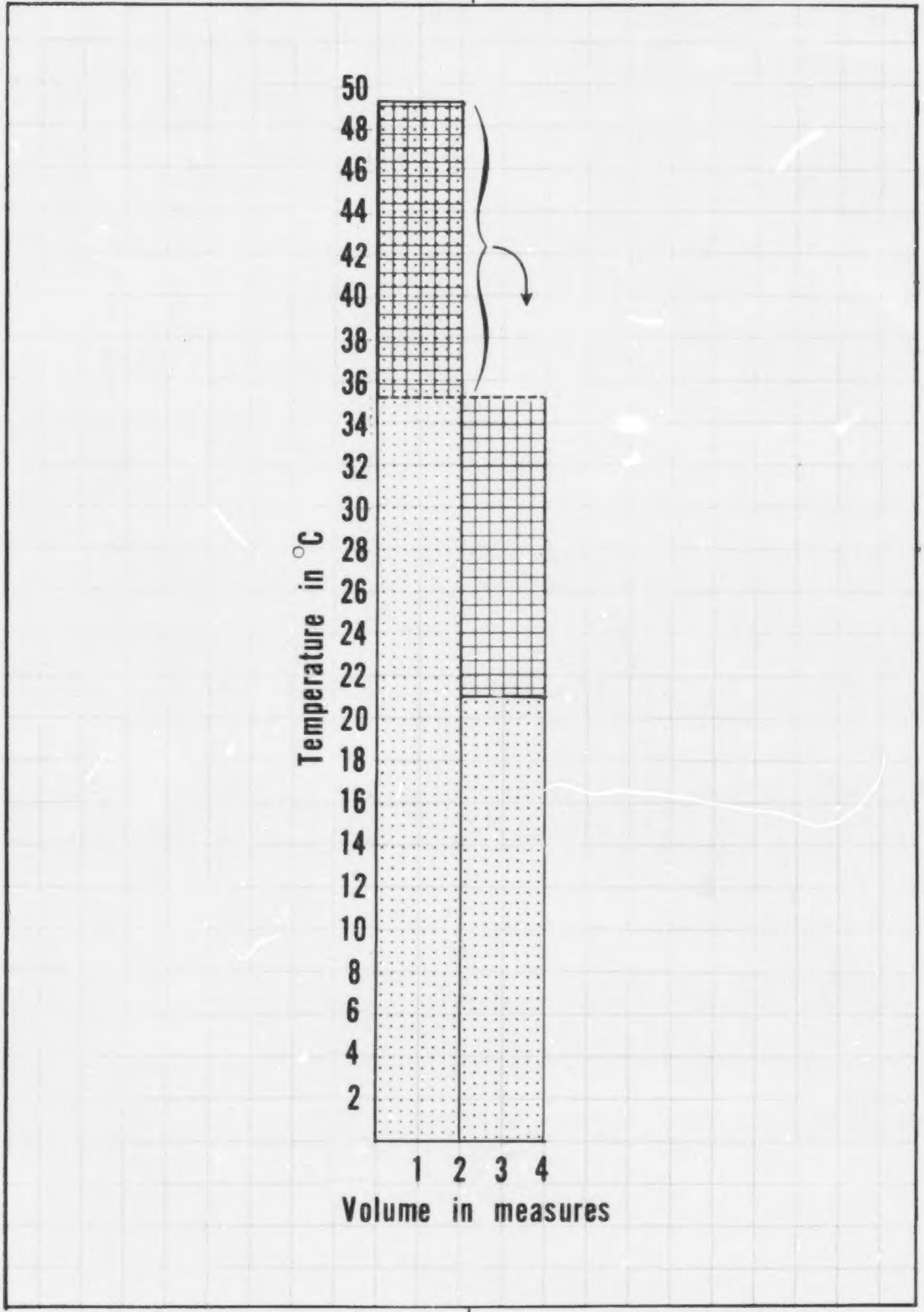
On a chalkboard or overhead projector grid, set up an example of the before-and-after graphs from the preceding Activity. (See page 265.) You will also need a grid for later discussions of coordinate graphing.

ALLOCATION OF TIME:

About 1-1/2 to 2 hours will be needed to complete this Activity. More time may be necessary if the children have not had the Heat Energy Transfer experiences in Grade 4.

TEACHING SEQUENCE	COMMENTARY
1. Have the children retrieve the before-and-after graphs they made to show how the h.e.u. were spread out as they mixed the 50°C water with the 20°C water. Refer to the sample before-and-after graphs you prepared. Looking at the two "before" graphs, indicate the temperature of the mixture on the graph of the hotter water. Draw a horizontal line there.	
• Does this agree with the height of the graph of the mixture?	It should!
Now transfer h.e.u. squares from the higher column to the lower one until the new graph is the height of the temperature found for the mixture. In effect the graphs are "evened off."	The width of the graph would be the same as that of the two separate sample graphs "pushed together."

TEACHING SEQUENCE	COMMENTARY



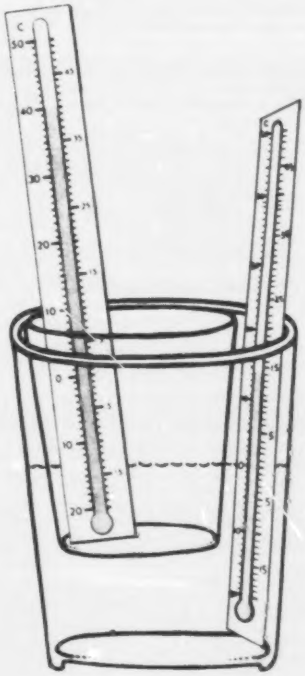
TEACHING SEQUENCE	COMMENTARY
• From this representation, which sample gave up h.e.u.? Which sample gained h.e.u.?	The hotter sample gave up h.e.u. and the cooler sample gained h.e.u.

TEACHING SEQUENCE	COMMENTARY
• What about the number of h.e.u. gained and lost?	The same number were given up by the hotter sample as were gained by the cooler one. As they have learned from previous experiments, the heat energy can be accounted for.
Now ask if this transfer might represent what happened when they mixed together the hot and cold samples of water.	Of course, in the physical mixing all the water from one sample mingled with that from the other. It would not have been easy to tell in what direction the transfer took place. In fact, some children may think, quite reasonably at this point, that the transfer is from a larger number of h.e.u. to a smaller.
• What if the two samples are *not* allowed to mix physically? (Show the children an experimental setup like the one they will be using.) How could you tell if the transfer was from a higher temperature sample to a lower *or* from a larger number of h.e.u. to a smaller?	See the illustration on page 272.
If the discussion does not bring up the idea of using two samples having the same temperature but different volumes, ask them what they would predict if a sample of 2 measures of 18°C water were placed in contact, but not mixed with, 1 measure of 18°C water.	The intent here is to provide the children with a brief review of Activities covered in Minisequence III of Grade 4 on the transfer of heat energy and to focus attention on the directional aspects of those experiences. If you feel that the children would benefit from a slower approach, consider taking up those Activities in sequence. For instance, you may want them to begin by investigating the transfer of h.e.u. between two samples of equal volume but different temperature. That would be a situation like that in Activity 2, but without the physical mixing.

TEACHING SEQUENCE

The children can continue to work in teams of two. Give each team two thermometers. Ask them to measure the temperature of the same region of the room with both thermometers.

If both thermometers do not show very nearly the same temperature after waiting a minute or two, the children should exchange the thermometers for others. Then they should place two measures of 18°C water in the smaller plastic (inner) cup, and one measure in the outer, polyfoam cup. Place a thermometer in each and read the temperature over a 5 minute period.



COMMENTARY

The purpose of this is to be certain that both thermometers in a pair are alike by seeing if they register the same room temperature.

Set out the containers of 18°C water.

They will find no change in temperature. This is similar to making a mix of two samples of water at the same temperature. (The temperature of the mix is the same as that of the individual samples.)

TEACHING SEQUENCE	COMMENTARY
• How many h.e.u. were in the larger, 2-measure sample? How many were in the smaller sample?	This would be 2 x 18 or 36 h.e.u. The smaller, 1-measure sample would contain 18 h.e.u.
• How would you interpret these results?	There must be a difference in temperature in order for any transfer of heat energy (or evening-off of sample graphs) to occur. In other words, the heights of the two graphs must be different. Here, the heights of the graphs of each sample remain the same, although the larger sample continues to possess twice the h.e.u. of the smaller because the double number of h.e.u. are spread out over the double volume.
2. Since there was no transfer of heat energy at all in the preceding situation, it is beginning to look as if such transfer occurs from a higher temperature sample to a lower. If so, what could be predicted in the following two situations?	
Situation 1: There is one measure of 36°C water in the inner cup and 2 measures of 18°C water in the outer cup. • How many h.e.u. will be in each cup? • Will there be a transfer of heat energy? If so, from where to where? Situation 2: There is one measure of 36°C water in the inner cup and 3 measures of 18°C water in the outer cup. (The same questions can be asked as above.)	Encourage the children to express their predictions as to heat transfer. Shortly they will experiment to find out what will happen. In the first situation, although each sample has the same number of h.e.u. (36), heat energy will be transferred because there is a temperature difference. There is also a temperature difference in Situation 2, but in this instance the colder sample actually has more h.e.u. because of its larger volume.
Now assign half the teams to investigate Situation 1 and	

TEACHING SEQUENCE	COMMENTARY
the other half situation 2. Each team should obtain a copy of Worksheet IV-1 and graph paper.	Note that the data will consist of temperature readings on each cup every half minute.
• What do you expect the temperatures will be, say, after 1 minute?	By now, some children will predict that the cooler sample will get warmer, and the hotter sample will cool off.
• What do you think the final temperature will be?	Some may say that the final temperature will be "in the middle"; others may realize that it will not because in both cases there is more cold water than hot.
The teams can divide into one child who will observe the thermometers and one who will watch the clock, call "now" every minute, and record the thermometer readings as called out. When they are ready, the teams should put 1 unit measure of hot water in the plastic cup and the required measures (2 or 3) of cold water in the polyfoam cup, with a thermometer in each. Be sure that they stir each for a minute and record the two temperatures in the appropriate spaces for time "zero." Then they should place the smaller cup in the larger exactly when the clock shows a particular minute (i.e., when the second hand reaches 12). Thereafter, temperatures should be read and recorded every half minute. They should swirl the contents gently between readings.	If the classroom does not have a clock with an easily visible sweep second hand, it may be necessary to synchronize the teams and have one person with a sweep-second-hand watch call time for the whole class. The continued swirling is important to achieve equalization of temperature before too much exchange of heat energy with the room surrounding the system occurs. The children may need several reminders to keep the contents of the cups in motion.

WORKSHEET IV-1 Name:

Situation_____

TIME (minutes)	TEMPERATURE (°C)	
	outer-cup (colder sample)	inner cup (hotter sample)
0		
1/2		
1		
1-1/2		
2		
2-1/2		
3		
3-1/2		
4		
4-1/2		
5		

Colder Sample:

BEFORE

Temp._____°C

Volume_____

h.e.u._____

AFTER

Temp._____°C

Volume_____

h.e.u._____

Hotter Sample:

BEFORE

Temp._____°C

Volume_____

h.e.u._____

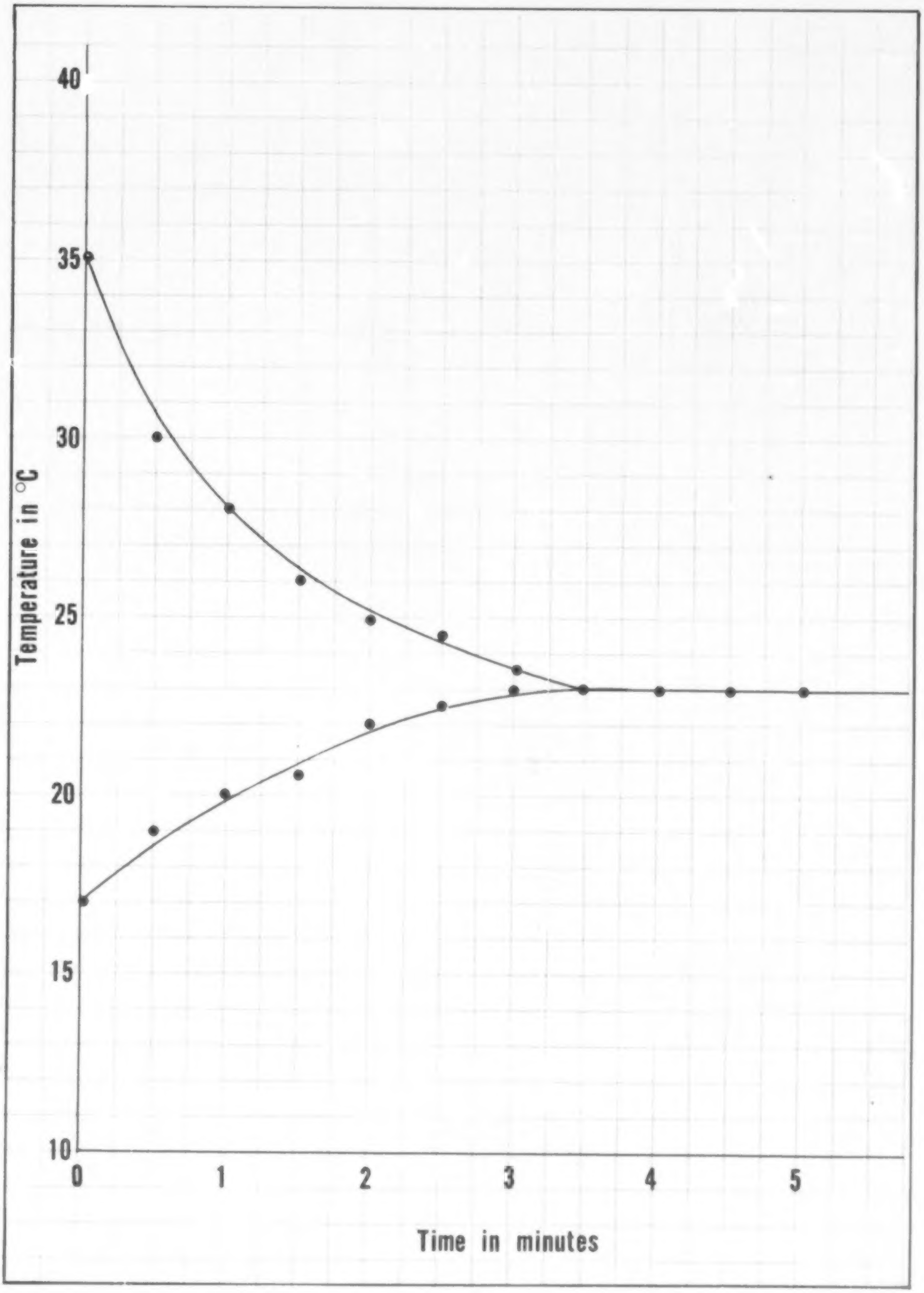
AFTER

Temp._____°C

Volume_____

h.e.u._____

TEACHING SEQUENCE	COMMENTARY
	(Stirring the contents of the cup is difficult, especially in the outer cup where there is such a small space. It may also cause the thermometer stems to slip against their backing.)
Select typical data to place on the chalkboard from each experiment.	
• Did the final temperature agree with what you expected?	Since the final temperature is not in the middle, some children may be surprised.
Now have each child enter the actual data he or she obtained on a coordinate graph. Distribute graph paper and then, following the children's suggestions, label and number the axes of the grid on the chalkboard or overhead projector. Next ask one of the children to show where one of the data points should be placed. Follow this with the plotting of a few other sample points from the data table on the board. They should then be able to work on their own.	Coordinate graphing was introduced in Grade 4. If the children are not skilled in such representations, please refer to the introductory Activity of Minisequence III in Grade 4. The data for both the outer and inner cup sould be plotted on the same graph. They can use different colored pencils or crayons for the two sets of points.
Once the data have been entered, each child should draw the "best trend" lines through the two sets of points.	• Note that a trend line need not go through every point. In these cases it is a smooth curve where as many points might lie above as below the line. A sample graph for Situation 1 is shown on page 277.
3. The trend lines on the graph seem to suggest that the hot water decreased in temperature faster than the cold water increased in temperature. Ask the children what they think happened to	


Temperature in °C
40
35
30
25
20
15
10
0
1
2
3
4
5
Time in minutes

TEACHING SEQUENCE	COMMENTARY
the heat energy in the hotter water and the colder water over the period of time:	
• What became of the h.e.u. in the hot sample? Where did the new h.e.u. gained by the cold sample come from?	The children should suggest that some of the h.e.u. in the hot sample were acquired by the cold sample.
• How could you find out how many h.e.u. were lost by the hot water and how many were gained by the cold water?	The number of h.e.u. lost and gained could be determined by making V-T graphs before and after the transfer took place. If you feel the children would benefit from making the bar graphs and actually counting the h.e.u., consider using Worksheet III-4 in the Grade 4 Teacher's Guide. However, most children will be able to calculate the h.e.u. arithmetically at the bottom of Worksheet IV-1.
Begin by considering Situation 1. Sample data and calculations are given below:	

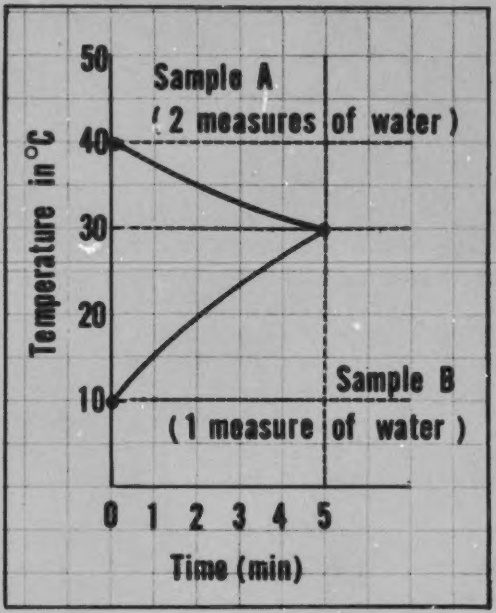
Colder Sample:		Hotter Sample:	
BEFORE	AFTER	BEFORE	AFTER
Temp. 17°C	Temp. 23°C	Temp. 35°C	Temp. 23°C
Vol. 2 measures	Vol. 2 measures	Vol. 1 measure	Vol. 1 measure
h.e.u. 34	h.e.u. 46	h.e.u. 35	h.e.u. 23

Number of h.e.u. gained 12

Number of h.e.u. lost 12

• In which direction was the heat energy transferred?	They should respond that the transfer was from the sample at the higher temperature to the one at the lower--exactly as before. However, in this situation, both samples contained about the same number of h.e.u. to begin with.
Next consider Situation 2. Here are some sample data and calculations:	

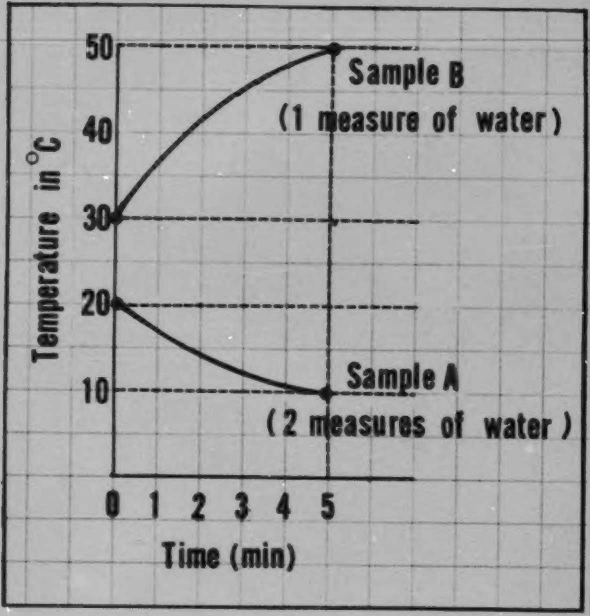
TEACHING SEQUENCE	COMMENTARY
Colder Sample: BEFORE: Temp. 19°C, Vol. 3 measures, h.e.u. 57 AFTER: Temp. 23°C, Vol. 3 measures, h.e.u. 69 Number of h.e.u. gained 12	**Hotter Sample:** BEFORE: Temp. 36°C, Vol. 1 measure, h.e.u. 36 AFTER: Temp. 25°C, Vol. 1 measure, h.e.u. 25 Number of h.e.u. lost 11
	Notice that in this case the number of h.e.u. lost by the hotter sample is 1 less that the number gained by the colder sample. Sometimes these two numbers may differ by even more because of "losses", i.e., interaction between this "open" system and the air surrounding it over the 5-minute interval.
• Which sample lost heat energy? Which one gained heat energy?	In this situation, the colder sample gained heat energy despite the fact that it had more than the hotter sample to begin with.
• In which direction was the heat energy transferred?	Again the heat energy was transferred from the higher temperature sample to the lower.
• How did you know?	The temperature of the hotter sample went down while that of the colder one increased.
Help the children come to the conclusion that heat energy is transferred when there are differences in temperature--even if the colder sample has more heat energy initially.	
• Was heat energy conserved?	Yes--what was given up by the hotter sample was gained by the colder one.
• When did the transfer stop?	When the temperatures became equal.
4. Draw a simplified graph like the following one on the	

TEACHING SEQUENCE	COMMENTARY
chalkboard or overhead projector:  	
Point out that the graph represents two samples put in cups just as in the experiments they have observed.	
Ask if the graph seems all right.	The children may say that the lines come together too quickly or two slowly, or they may make other comments about the shape of the lines.
Direct their attention to the initial and final temperatures and to the sizes of the two samples and ask if the amounts of heat energy gained and lost agree.	By this time many children should be able to calculate h.e.u. quickly.
When the children do the computations, they will find that Sample A had 40 x 2 = 80 h.e.u. at 0 minutes and 30 x 2 = 60 h.e.u. at 5 minutes. Therefore it lost 20 h.e.u. Sample B went from 10 x 1 = 10 h.e.u. to 30 x 1 = 30 h.e.u.	

TEACHING SEQUENCE

It gained 20 h.e.u. In other words, the amount gained by one sample agrees with the amount lost by the other. Thus the graph might represent the results of an actual experiment.

Now draw another simplified graph:



With the children, calculate that Sample A goes from 20 x 2 = 40 h.e.u. to 10 x 2 = 20 h.e.u. Therefore, Sample A loses 20 h.e.u. Sample B goes from 30 x 1 = 30 h.e.u. to 50 x 1 = 50 h.e.u., gaining 20 h.e.u.

Ask if the graph represents a possible experiment like the one they observed in the early part of this Activity. If the children disagree about the graph, let them explain and discuss their ideas.

COMMENTARY

Here the children will see a graph for which calculations of h.e.u. give the usual results: the amount gained by one sample is equal to the amount lost by the other. Nevertheless, the graph does not represent a reasonable set of results because the heat energy is shown being transferred from the colder sample to the hotter sample.

Some of the children will probably say that the graph is reasonable since the heat energy gained equals the heat energy lost. But others should see that the graph does not make sense since the heat goes from the colder sample to the warmer.

TEACHING SEQUENCE	COMMENTARY
If they do not come to the conclusion that something is wrong with the graph, have them tell you what it shows. Which sample is hotter at the start? Which sample gains heat energy? Is the heat energy transferred in the way you would expect?	Sample B is hotter. But it gains heat energy. In the graph, the heat energy is not transferred from hot to cold as one would expect.
If some children are still not convinced that the graph is wrong, let them set up an experiment to test it taking a plastic cup and a polyfoam cup, putting a 1-measure sample of 30°C water in one and a 2-measure sample of 20°C water in the other and continuing as in the early part of this Activity. The resulting coordinate graph will not look like the one in the illustration.	The point of this section is that a heat energy transfer graph of this sort can be wrong even if the number of h.e.u. is right. That is, conservation of energy is not the whole story. The direction of the spreading out of energy is also involved. Heat energy flows from regions of high temperature to regions of low temperature--an example of the "degradation of energy."

Activity 4 From Higher Concentrations to Lower Concentrations

When a high concentration of molecules is placed within a system in which the molecules can move, the natural tendency is for them to spread out through the available space. In the previous Activity, attention was focussed on the evening out of temperatures. The children observed that heat energy was transferred from one part of a system to another in the direction of the lower temperature. In this Activity, similar observations and conclusions can be made about the two parts of a system--but in this case the evening out will be of the numbers of molecules of a substance in water. This property, the concentration, can be readily followed in this instance because the molecules are colored.

The children will be working with solutions of yellow and blue food coloring. They will follow the transfer of the dissolved molecules by the change in color in different parts of the system. The systems will consist of the colored solutions separated from clear water by the walls of a cellophane bag through which the molecules can move. The concept and the technique of working with these "molecular sieves" were introduced into the COPES curriculum in Grade 4. Here the children will observe that molecules spread out from regions of higher concentration to those of lower concentration--never the reverse. Once the concentration on either side of the cellophane walls is the same, no further change is noted. Hypotheses are developed to explain this condition of "equilibrium." Are the walls clogged? Can the molecules move only in one direction? When answers to these questions are pursued by the children, they find that even more dilute solutions will spread into the available water--the walls are not clogged. They also find that the molecules can move in either direction, but always towards the part of the system at the lower concentration. In the next Activity, they will simulate this behavior with a game of chance--"blind" selections of colored beans as they are exchanged between two cups.

MATERIALS AND EQUIPMENT:

1 bottle (1 oz) of blue food coloring

1 bottle (1/8 oz) of yellow food coloring

2 transparent containers of at least 1-liter (1-qt) volume

1	funnel, any size
4	containers, with pouring spouts, such as teapots or pitchers
1	sheet of filter paper or 2 paper towels to fit the funnel
1	pair of scissors
1	roll of cellophane tubing (about 3 cm (1-1/8 in. wide) (at least 600 cm (20 ft long)*
30	or more transparent plastic cups, or baby food jars
30	or more clothes pins
3-6	cups, 1-oz (approximately 30-ml), waxed paper or plastic (optional)
2-4	plastic sandwich-size bags with seals (optional)
	calcium chloride, about 1/4 lb (optional)

*The cellophane tubing used in this Activity is similar to that sometimes used as sausage casings and the same as that called for in Minisequence IV of Grade 4. It can be ordered from some butchers or from a scientific supply house where it will be listed as "Dialysis Membranes, Regenerative Cellulose Seamless Tubing." A 100-ft roll will be more than adequate for this Minisequence. Since about 20 feet are used, the 100-foot roll can be shared with other classes. Ordinary commercial cellophane will not work because it has a water-proof coating on it. Plastic wrap is a different material entirely and cannot be substituted for cellophane.

PREPARATION FOR TEACHING:

Make up a liter of blue solution by adding 1/4 teaspoon of blue food coloring to a liter of water. Place the dilute blue solution in 2 containers with pouring spouts. You will also be making up a liter of yellow solution in front of the class by adding 1/4 teaspoon of yellow food coloring to a liter of water.

Cut 30 pieces of cellophane tubing, each about 20 cm (8 in.) long. Allow the pieces to soak in water for at least 15 minutes prior to use.

If you will be doing the Extended Experience with the children, follow the directions for making the calcium chloride solution given there. That experiment, which must be observed for a long period of time, should be set up at the beginning of this

Activity.

ALLOCATION OF TIME:

The children will need about 1 to 1-1/2 hours of class time to complete this Activity. However, observations must be made over a period of several days even if the Extended Experience is not undertaken.

TEACHING SEQUENCE	COMMENTARY
1. Prepare the liter of yellow solution in front of the children. As you add the food color to the water, ask the children what they observe.	They should notice the spread of the yellow color throughout the water.
Focus their attention on the transparency of the solution. Can they see the molecules?	Not the individual ones. Only the color that a great many molecules impart to the solution.
• What if you filtered this solution? Would the liquid coming through contain the dissolved yellow molecules?	You might want to tell the children that food color is itself a very concentrated solution of colored molecules in some water and alcohol.
Set up the funnel and filter a small portion of the solution. Be sure all the children can observe the liquid coming through, which will be just as yellow as the original solution.	Place the remaining yellow solution in two containers with pouring spouts.
Pass around pieces of filter paper, or the paper toweling, and have the children hold this up to the light.	
• Can you observe any holes in it?	
• What can you say about the size of the yellow molecules compared with the holes in the paper?	The yellow molecules must be smaller since they were able to pass through. If the children have had experience

TEACHING SEQUENCE

Show the children the cellophane tubing, tell them that it acts like an even finer "sieve," and suggest that they see if the yellow and blue solutions will go through it.

Give each team of children a piece of moistened cellophane tubing. After the bottom knot is tied and the tubing blown up, one member of the team can pour in some (30 ml or 1 oz) of the dilute yellow solution from one of the containers with a pouring spout. The other team member can fill his or her cellophane bag with some of the dilute blue solution. After filling, have them carefully rinse off the outside with water (to ensure that no colored solution accidently spilled on the outer part of the bag). They can then place the bag in a cup of clear water with the open end clipped to the rim of the cup (or glass) with a clothespin.

Encourage the children to keep a record of the observations they make. Such a record might include:

Liquid inside the bag	Liquid outside the bag	Observations

COMMENTARY

separating different sized particles with sieves, they can see that the filter paper is functioning as a very fine sieve also.

The children can continue to work in pairs in this Activity. If you want them to work individually, alter the materials requirement accordingly.

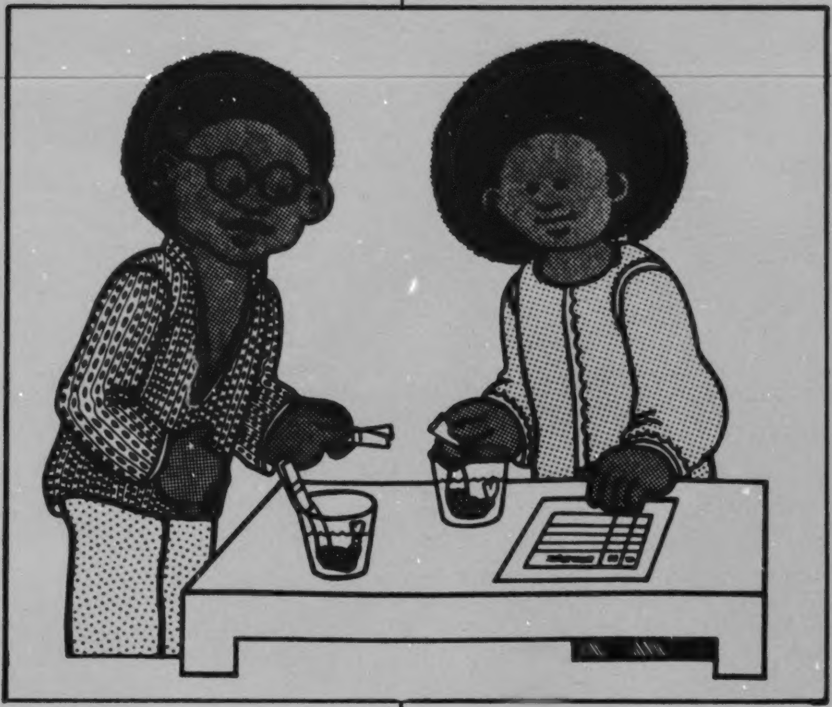
This tubing was used in Grade 4 Activities to help establish the existence of the tiny particles called molecules. If the children are not familiar with the techniques of tying off, opening, and filling the "bags," take some time to show them how: remove a soaked strip of cellophane tubing from the water. Tie off one end of the tubing about 1 in. (2.5 cm) from the end. Do this by making a knot in the tubing itself. Rub it between your fingers until the sides become separated from each other. You can then blow into the tubing to open it.

TEACHING SEQUENCE

Have them observe their solutions from time to time over a period of a few hours to see what happens.

COMMENTARY

This part of the Activity will require only a short time to set up, but observations should be made over a period of several hours or the next day.



TEACHING SEQUENCE

2. Ask the children first to describe and then to explain what they saw.

- What do you think happened?

COMMENTARY

The children will have observed that both the blue and the yellow colors have appeared in the water outside their respective bags. The yellow, however, should have appeared outside before the blue.

Based on their observations, some of the colored molecules appear to have moved from inside the bag to the outside.

TEACHING SEQUENCE	COMMENTARY
	If some think that there is leakage of the solution through the knot, have them fill another bag and insert it in a cup so that both ends are sticking up. (No knot will be in contact with the surrounding water.) They will observe the color outside the bag even with this setup.
After the children lift the bags out of the cups, ask:	
• Do you observe any difference in color compared to the solution you started with?	At this point it would be advisable to have one tube with the original yellow solution and one with the original blue solution for comparison. Depending upon how long the experiment was running, they may observe that the color inside the bag has become lighter than the control.
• Where did the colored molecules go?	Through the walls of the bag and into the water surrounding it.
• Do molecules always move from inside to outside the bag? How could you find out?	The cellophane bags may be rinsed and reused. If allowed to dry, care must be taken not to bend the cellophane because it will be brittle and may crack. But once rinsed, the bags can be kept for a period of time moistened. (They cannot be kept indefinitely in water since mold may grow.)
To find out, they should suggest reversing the procedure: place clear water in the bags and colored solutions in the cups.	The team members may alternate the colored solution each works with. Again, these molecular sieving experiments take time. The children will have to observe their setup over a period of hours, or the next day.

TEACHING SEQUENCE	COMMENTARY
3. Again ask the children to describe what they saw and then try to explain it.	In this experiment, they will have to lift out the bag to observe changes since the surrounding liquid is colored and thus it is not possible to view any changes in the bag.
• What changes occured over time?	The color lightened in the cup; the clear water in the bag became colored.
• What can you infer might be happening?	Apparently the colored dissolved molecules are again moving through the walls and into the clear water.
• When might this process stop? Since the colored molecules are moving into the bag, do you think they will all land inside the bag?	Encourage them to allow this experiment to continue for several days to see what further changes might take place. Actually, once the concentration (number of colored molecules in a unit volume of solution) becomes equal in both parts of the system, no further change will be evident. Movement may occur back and forth across the walls, but whatever goes in will be countered by what goes out. The net effect will be no observed change. The system is in equilibrium. The molecules have spread themselves out evenly over the available space.
4. After several days, the children should find that with either system (the blue or the yellow), no further change is evident.	Since they might be observing through different amounts of colored solution, the only way they could be sure that the two parts of the system eventually end up in equal concentrations is to remove the same amounts of liquid from the cup and from the bag and compare their color. This can be conveniently done by pouring

TEACHING SEQUENCE	COMMENTARY
	a small amount of each into a 1-oz cup. If the cups are white, all they need do is observe each side by side from above. If the cups are transparent, place them on white paper.
Does this observation mean that the colored molecules can't move through the walls anymore? Why do they think no more color change is observed?	Responses might include, quite correctly, that only when concentrations are different will there be movement across the membrane, (just as only when temperatures are different will there be a flow of heat energy) but don't press for this answer. Some may respond that the walls are clogged!
Now give the children access to more cellophane tubing (rinsed will be fine), blue and yellow solutions, and transparent cups. Encourage them to use the materials to help answer any questions or hypotheses they might have about the conditions under which molecules move through the cellophane walls. The following are some questions you might raise if they are not generated by the children: • What will happen if the lighter solution in the bag (after it has come to equilibrium with the surrounding solution) is placed in clear water? Will the colored molecules move across the walls or will they spread themselves out even thinner over the bag and the surrounding water?	The way in which you conduct this part of the Activity will depend somewhat on your own style as well as on the children's inclinations. Hopefully, they will have at least one or two ideas of their own which they wish to investigate. They may discover each of the possibilities which are suggested on the left, as well as others. They will find that there is a transfer of more colored molecules into the clear water.

TEACHING SEQUENCE	COMMENTARY
• How long will this continue? If they keep placing lighter bags in clear water, will the color inside the bag ever get darker?	They will find that movement is always from the higher concentration of color to the lower.
• If a lighter colored solution is placed in a bag which is then immersed in a darker solution rather than in clear water, will the molecules continue to move out of the bag?	No--the colored molecules will move in, until equilibrium is reached.
• Do the molecules in both the yellow and the blue solutions behave in a similar manner?	Yes.
• What happens if the blue solution is placed in the bag and the yellow solution in the surrounding cup, or vice versa?	The blue and the yellow will both cross the membrane, forming a green colored solution in the bag and in the cup.
• What happens if the blue and yellow solutions are mixed together, placed in the bag and the bag is then placed in clear water?	Both the blue and the yellow particles will go out of the bag into the water, the yellow before the blue, just as if they were in the separate bags.
5. Discuss the results obtained in any of the above experiments which were performed by the children. If new questions are raised, you may wish to provide more time for experimentation.	Most of the discussion can and should follow the children's interests. The conceptual purpose of the Activity will have been served if the children learn that the (net) flow of colored molecules is from the region where they are more concentrated to the region where they are less concentrated. If two kinds of colored molecules are concentrated in two different places (e.g., yellow in the bag and blue outside), they will observe that the yellow molecules will move away from the space where they are concentrated; similarly, the blue will move into the space

TEACHING SEQUENCE

Finally, fill two cellophane bags with blue solution. Place one in a cup of the same blue solution and another in a cup of yellow solution. Show these to the class and ask the children to predict what will happen in each case.

Ask how it can be that blue comes out of the first bag and not out of the second. Does this make sense? Do the blue molecules "know" the difference between the yellow molecules and the blue ones that are outside?

You may consider asking the children why they think the colored molecules move from regions of higher concentration to regions of lower concentration. You might also want to consider asking them if they see any similarities between the transfer of the colored particles and the transfer of heat energy in the preceding Activity. Do not look for answers, nor give them answers. Encourage them to express their ideas.

COMMENTARY

where the blue is dilute.

They will probably predict that nothing will happen in the first case and that blue color will come out and yellow color go in to make green in the second case.

Do not answer these questions, nor indicate that later activities will provide a model to help answer them. Some child may suggest that perhaps blue does come out in both cases, but that it is not seen in the first case because just as much blue goes in. If so, have the class consider the suggestion. They should see that it is at least a reasonable possibility, and would eliminate the need for the molecules to "see" each other.

The children may not yet sense the similarities in the observation that when concentrations were different, there was movement across the cellophane membrane; when temperatures were different, there was a movement of heat energy across the plastic cup. Also, both transfers stopped when the temperatures or concentrations

TEACHING SEQUENCE

COMMENTARY

became equal. Could higher temperature substances somehow be considered to be at a higher "concentration?" If so, a higher concentration of what? The children will consider these similarities again in the next Activity.

EXTENDED EXPERIENCE:

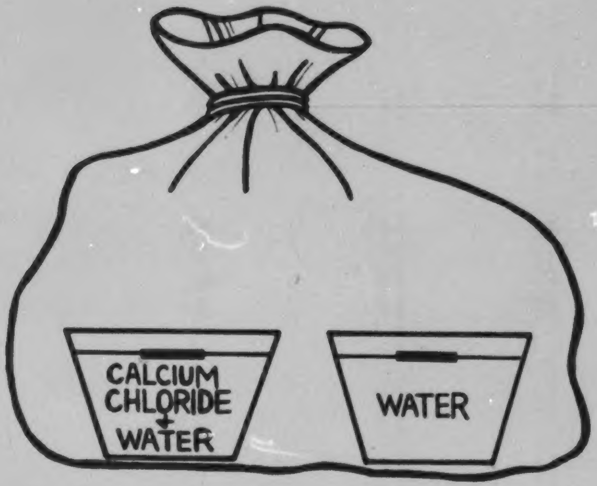
An interesting experiment can be set up that will reinforce the idea that within a system, a solution will tend to become more dilute if water is available, just as the colored solution did. A 1-oz (30-ml) cup of water and a 1-oz cup of saturated calcium chloride solution can be made into one system by placing the cups in a plastic bag which is then sealed to isolate it from the surrounding air. Over the period of observation, which must be at least two weeks, the children will observe the gradual transfer of water into the salt solution, resulting in its dilution. Eventually, all the water will become part of the salt solution! This phenomenon adds to the increasing evidence that concentrations of molecules naturally tend to spread out to become evenly distributed. The difference here is that only the water molecules can transfer--in the form of water vapor within the sealed bag.

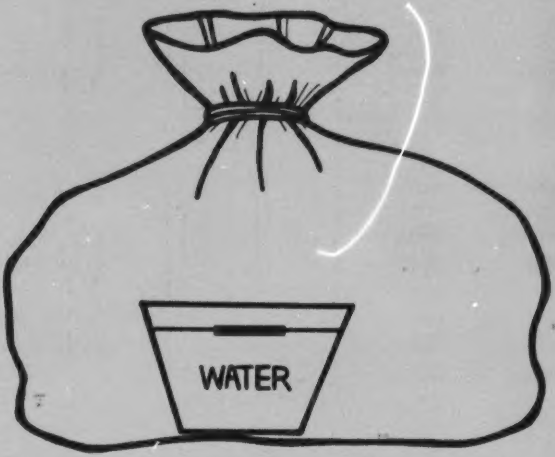
As indicated in the Preparation for Teaching, it is suggested that the experiment be run concurrently with the others in this Activity. Periodic observation of the cups, which should be set aside in the classroom where they will not be disturbed, can be made on into the following Activity and beyond, if necessary.

Start to prepare a saturated solution of calcium chloride at least the day before the children will need to use it. Keep on adding solid, while stirring, until some appears not to dissolve. The next day, or after several hours, try to dissolve more. Once you are sure no more will dissolve, let it cool to room temperature. (If it is dehydrated, the salt will initially use some water to re-form the hydrate salt, with, of course, the liberation of heat; if it is hydrated to start with, you may want to use warm water to make the solution, in order to ensure saturation.) The solution may form a scum on top, which will not interfere. Two oz of water, more than enough for two setups, will absorb about 1/4 lb of calcium chloride, which is extremely soluble.

The children can set up their bag systems as follows: In one--the control--have them place 1-oz cup of water alone. The cup should be filled so that the level is about 1/2 cm from the top.

Have them mark the water level on the outside with a crayon. This will serve as a measure of the amount of water at the start of the experiment. The cup of water should then be placed in a sealed plastic bag. In the second plastic bag, they should place a 1-oz cup of water, filled to the same (marked) level and a cup of the saturated calcium chloride solution. This cup also should be filled to about 1/2 cm from the top and its initial level marked on the outside of the cup. This bag, too, should be sealed.





After at least 2 weeks, the children can report their observations. There should be no observable change in the water level in the control cup. In the other system, the water level will be lower and the solution level higher. After several more weeks, almost all the water from the cup of plain water will have transferred to the cup with the solution--it may even overflow!

How does this situation compare with the transfer of the food coloring? In both instances there appeared to be a movement from a high concentration to a lower one. But in the case of the food colors, both the water and the food color molecules could move. Here only the water molecules moved. Help the children see that in both cases, the end result was that a more dilute mixture resulted. The calcium chloride molecules, or the food color, were distributed among more water molecules. This situation is an additional example of the natural tendency of concentrations of substances or of energy to dissipate.

Activity 5 A Model of the Transfer

In this Activity a model of the transfer of the colored molecules from regions of high concentration to regions of lower concentration is presented in the form of a game of chance. In the game "blind" exchanges are made between two cups of beans: Initially one cup contains blue and white beans, simulating the blue solution; the other contains only white beans, simulating water alone. Eventually after a few exchanges, the children observe that the numbers of blue and white beans tend to even out between the two cups. Furthermore, a graph of the numbers of blue beans in each cup as the exchanges take place results in a representation very much like the one made in Activity 3--the one showing the change in temperature with time when hot and cold water samples are placed in thermal contact. By means of this bean-exchange model, the children are helped to come to the idea that the transfers of heat energy and of the dissolved colored molecules might both result from chance exchanges. What is observed--the less concentrated region gaining from the more highly concentrated region--is the net result. The children also use the model to help explain the unidirectional character of these transfers, another major concept in the Degradation of Energy.

MATERIALS AND EQUIPMENT:

1	lb of Navy (pea) beans
1	aerosol can of blue paint
32	cups or glasses, transparent, (The "old-fashioned" glasses suggested for use in Minisequence II would be a good choice.)
1	glass-marking pencil
30	copies of Worksheet IV-2
60	pieces of graph paper, 4 sq/in. (or 2/cm)
30	copies of Worksheet IV-3

PREPARATION FOR TEACHING:

Start the preparation a few days before you plan to do this

Activity: Place about one quarter of the beans, (1/4 lb), in a large, shallow box in a ventilated area. Spray them with blue paint. After the paint has dried thoroughly, stir the beans to expose their unpainted sides and respray them. By repeating this a few times you can get a group of blue beans which are clearly distinguishable from ordinary white beans. Each team will need 60 white (unpainted) beans and 20 blue ones. You may consider substituting white (or colorless) marbles and blue marbles for the beans if you have a sufficient supply. It is important that the "feel" of the white and blue objects be the same so as not to influence the "blind" selection. If any of the blue or white beans are much smaller or larger than average, they should be discarded. You might ask a few children to help you quickly sort out such beans. They can also help by numbering half the cups with a "1" and the other half with a "2".

ALLOCATION OF TIME:

The children will need 1-1/2 to 2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Suggest to the children that in attempting to explain the observations they made in the preceding Activity it might be helpful to develop a model of how the colored molecules might have moved from one part of the system to another.	The intent of this Activity to provide a plausible, large-scale model to help explain the observations made in Activities 1-4 of this sequence. However, the children begin by attempting to account only for the transfer of food color from regions of higher concentration to regions of lower concentration.
• When you began the experiment with blue food color in the cellophane bag, what did the system look like?	The cellophane bag contained blue solution; the outer liquid was clear water.
Show the children the supplies of white beans and blue beans.	
• How might the beans be set up to represent this system?	Some may suggest that the blue beans be put in one place and the white in another. If so, ask if one part of the experimental system contained only blue molecules.
Eventually the children should arrive at the suggestion that the water could be represented	

TEACHING SEQUENCE

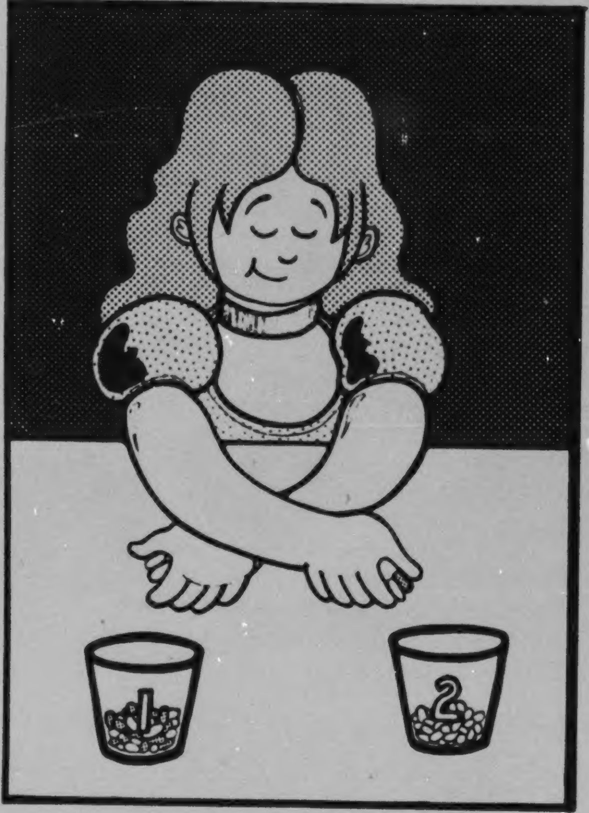
by the white beans and the blue solution by a mixture of blue and white beans. Then ask two children to help set up such a representation so that everyone can see it: Have one child count twenty blue beans and twenty white beans and put them in a cup numbered 1. Ask another child to count out forty white beans and put them in a cup numbered 2.

When the two children have finished counting out the beans, have one of them close his or her eyes while the other gives both cups a stir to mix the beans. Then have the first child reach one hand into each cup, take out two beans from each and place them in the opposite cups.

After the cups are again stirred, and again without

COMMENTARY

After this first exchange, 4 beans will have changed places.



TEACHING SEQUENCE

looking, the first child should switch two more beans from each cup to the other. At this point have the second child count the number of blue beans in each cup and report the result to the class. Then repeat the above procedure, with a third and fourth exchange of two beans each way. Again have the number of blue beans in each cup counted and reported to the class.

Ask the children what they expect to happen to the "blue bean count" in each cup as more and more exchanges are made. Ask them how certain they are of their predictions and whether they think everyone would get the same results if they tried the same experiment.

2. Once the children are sure of the procedure for setting up the cups and for the exchange of the beans between the cups, they can perform the experiment, in teams of two. Each team will need 60 white beans, 20 blue beans and two cups, (numbered 1 and 2). They will also need two copies of Worksheet IV-2. They should count and record the number of blue beans remaining in cup 1 and those appearing in cup 2 only after every two exchanges of four beans. Be sure they realize they must share the task of making blind selections from the cups and that the beans should be mixed in each cup before a selection is made.

Let the children discuss the results they observed as they performed the repeated

COMMENTARY

As the children are "blind selecting" the blue or white beans and shifting them, refer to the shift of blue food color molecules or the shift of water molecules.

After the fourth exchange, a total of 16 beans will have changed places.

They will probably expect the beans to become mixed in both cups. But some may expect something else, such as all the blue beans moving to cup 2.

If the exchanges are done properly, there will always be 40 beans in each cup. If they find that there are more or less than that number in either of the cups at any point, they can take out the extra beans from the cup having more by blind selection. They will then have an equal number of beans in each cup again.

No doubt the children will have noticed that the colors became "mixed up" as the

WORKSHEET IV-2 Name:

NUMBER OF EXCHANGES OF FOUR BEANS	NUMBER OF BLUE BEANS IN	
	CUP 1	CUP 2

TEACHING SEQUENCE

exchanges of beans between the two cups. Below is a set of sample data from an actual experiment:

NUMBER OF EXCHANGES OF FOUR BEANS	NUMBER OF BLUE BEANS IN: CUP 1	CUP 2
0	20	0
2	18	2
4	15	5
6	14	6
8	12	8
10	12	8
12	12	8
14	11	9
16	12	8
18	11	9
20	12	8

If no one mentions the similarity between this and the experiment with the blue food color, you can ask how the results compare with that experiment. This should lead to the realization that just as in the preceding Activity, the net transfer of blue color is away from the region of higher concentration and toward the region of lower concentration. Thus it seems to be a good model. In the previous case, it was the transfer of invisible blue unit particles or molecules; here it is blue colored beans.

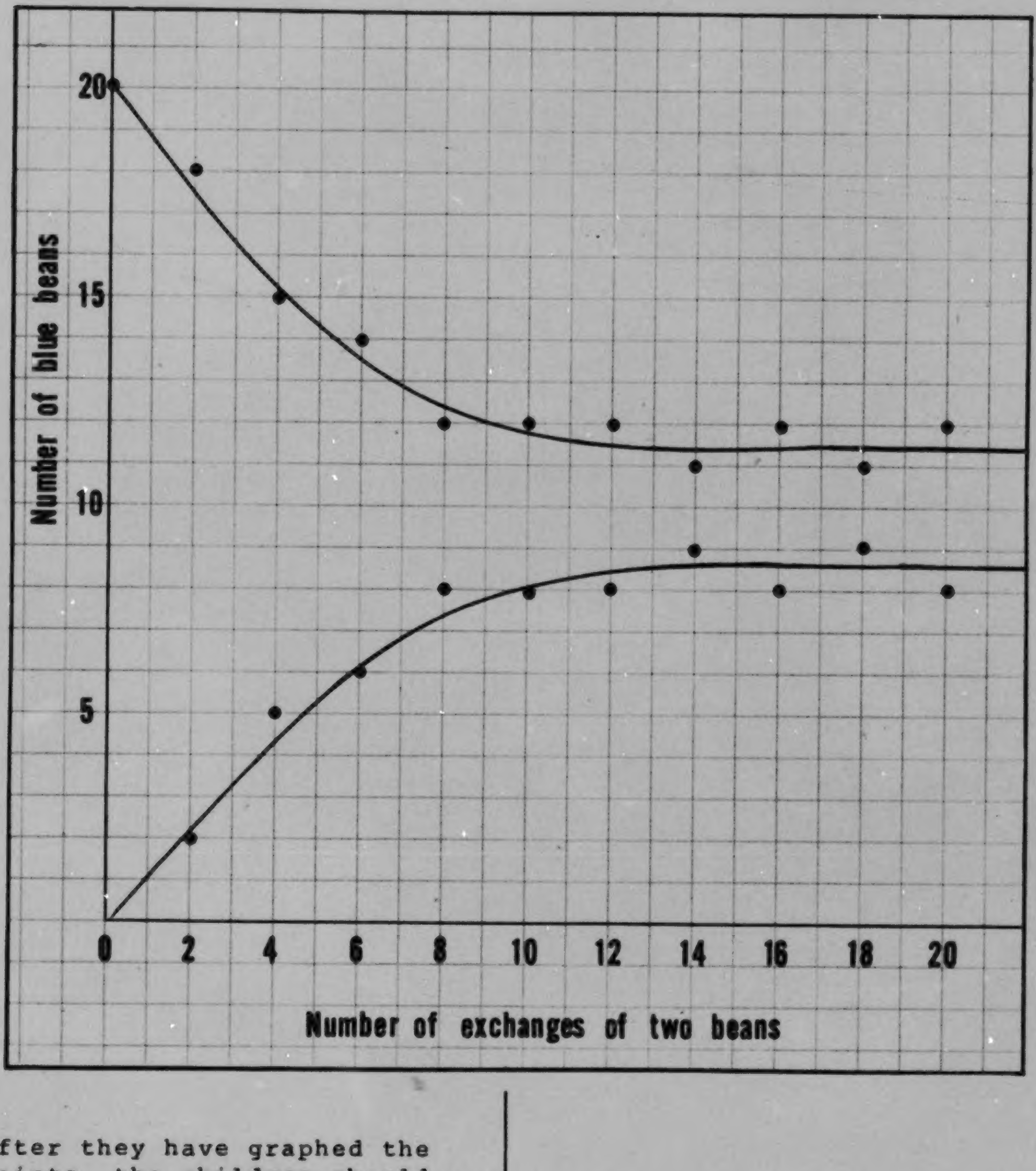
COMMENTARY

exchanging went on. Perhaps they will also have noticed that the final distribution of blue beans stayed close to being equally divided between the two cups.

TEACHING SEQUENCE

COMMENTARY

3. Next, distribute graph paper and ask the children to graph their data. They should use different colored pencils or crayons for the two sets of points.



After they have graphed the points, the children should try to draw the best smooth

TEACHING SEQUENCE

curves passing through or near most of the points, as shown in the illustration. When they do, most of them will realize that they drew similar "trend lines" in Activity 3 when graphing the data on temperature changes as heat energy was transferred between two cups of water. However, the children may point out that in some cases--as in the illustrated data--the trend lines don't "come together" completely as they did previously. They also may be puzzled by the way in which the data "jump back and forth" towards the end of the exchanges. If not, you might ask:

- What do the individual counts show at the 16th, 18th or 20th exchanges? Do the counts remain steady or do they appear to fluctuate?
- Why do you think this is so?

Some of the children may think that they "stopped too soon"--if they carried out more exchanges, the same number of blue beans would eventually end up in each cup. Such children may be interested in continuing the mixing beyond twenty to thirty or even more exchanges. Encourage them to do so.

COMMENTARY

The children may point out that four beans are moving back and forth at each exchange. Since the individual cups contain only 40 beans, this is a large proportion of a small sample. Also, by chance, the number of blue beans taken out of one cup may be counterbalanced exactly by the number put in from the other cup.

This kind of experiment will show that once the colors become mixed, little more change

TEACHING SEQUENCE	COMMENTARY
	is observed. That is, even though exchanges are still taking place between the cups, the ratio of blues to whites in each cup remains about the same. If you did not know that beans were being transferred, but only looked at the two cups over periods of time, you might infer that "nothing was happening." Thus, this would provide a nice opportunity for a discussion of the idea of equilibrium or a "steady state."
• What if the sample and the number of exchanges were larger? Would the final fluctuations be as large?	There would always be fluctuation but this is one way it could be minimized. If you wish, and if some children are interested, they might increase all the numbers of beans by a factor of five and then try repeating the experiment. In other words, they would put 100 blue and 100 white beans in one cup and 200 white beans in the other; and they would transfer 20 beans instead of four beans in each exchange. Then they can graph the results. They will find that this gives reasonably smooth lines of points similar to the results of averaging in the next Section. The fluctuation will be a much smaller fraction of the total number of blue beans in the larger sample.
• How could you achieve the effect of a larger sample with the data you have already taken?	The children could combine and average the data for several teams. As the children have learned in earlier grades of COPES, the averages of several measurements provide more reliable results than any one individual measurement. (See, e.g., Activity 5 of Minisequence V in Grade 5 and the sequence on "Averaging and Sampling" in Grade 3.)

TEACHING SEQUENCE	COMMENTARY
4. Divide the class into groups of five. Pairs of children who worked together in the previous Sections should be separated so that each group will have five different sets of data. Give the children copies of Worksheet IV-3. On it they can fill in the five sets of data that members of their group took in Section 2, above. The results can then be averaged in whatever way they wish.	To insure accuracy they will probably want at least two people to make each calculation of an average. An example of a filled-in Worksheet is shown on page 306.
After the groups of children have calculated the averages for each of the points, they can graph their average results in the same way that they previously graphed the original results.	The averages will show a smoother trend of change in blue bean concentration and a closer approximation to an even distribution of blue beans in both cups. In other words, this graph will look even more like the one constructed in Activity 3.
• How does this graph compare with the one which showed temperature changes as heat energy was transferred between two cups of water?	It is very similar.
Ask the children whether there might be some reason for the graphs to be similar in the two activities.	As they compare the two activities, the children should realize that both involved mixing--one, the mixing of heat energy and the other, the mixing of blue beans. In both the (net) flow was from a higher temperature or concentration to a lower temperature or concentration. Finally, in both cases, the transfer slowed as the concentrations became nearly the same (approached equilibrium).

WORKSHEET IV-3

Name:

NUMBER OF BLUE BEANS IN CUP 1						
NUMBER OF EX-CHANGES OF FOUR BEANS	DATA TAKEN BY:					AVERAGE

NUMBER OF BLUE BEANS IN CUP 2						
NUMBER OF EX-CHANGES OF FOUR BEANS	DATA TAKEN BY:					AVERAGE

WORKSHEET IV-3 Name: Alan

NUMBER OF EXCHANGES OF FOUR BEANS	NUMBER OF BLUE BEANS IN CUP 1 — DATA TAKEN BY: ARNIE	JAN	KATHY	MORRIS	DARRELL	AVERAGE
0	20	20	20	20	20	20.0
2	18	17	17	17	18	17.4
4	15	16	15	16	16	15.6
6	14	15	14	14	15	14.4
8	12	14	13	15	14	13.6
10	12	13	13	13	13	12.8
12	12	13	12	12	12	12.2
14	11	13	11	13	14	12.4
16	12	13	10	12	12	11.8
18	11	12	10	11	11	11.0
20	12	13	8	11	10	10.8

NUMBER OF EXCHANGES OF FOUR BEANS	NUMBER OF BLUE BEANS IN CUP 2 — DATA TAKEN BY: ARNIE	JAN	KATHY	MORRIS	DARRELL	AVERAGE
0	0	0	0	0	0	0
2	2	3	3	3	2	2.6
4	5	4	5	4	4	4.4
6	6	5	6	6	5	5.6
8	8	6	7	5	6	6.4
10	8	7	7	7	7	7.2
12	8	7	8	8	8	7.5
14	9	7	9	7	6	7.6
16	8	7	10	8	8	8.2
18	9	8	10	9	9	9.0
20	8	7	12	9	10	9.2

TEACHING SEQUENCE	COMMENTARY
• Do you think this bean-exchange model could be used to explain the transfer of heat energy from one part of a system to another? In what sense could a higher temperature be considered a higher concentration?	Apparently this model can be used to explain those phenomena. In Minisequence III of Grade 5 the children learned that the molecules of a substance at a higher temperature are more energetic then those of the substance at a lower temperature. Thus it is reasonable to think of the higher temperature water in the earlier experiment as containing a higher concentration of more energetic molecules than did the lower temperature water.
• Based on this model, do you think it would be possible to get all the blue beans back into one cup?	The children have found that after a point, continued exchanges of beans lead to no appreciable change in the distribution of the blue beans. They stay mixed in the same proportions. Making chance or random selections, the trend is irreversible. Of course, if they opened their eyes they could pick out the blue beans and put them back in the cup they were in originally, but this procedure is not analogous to what happens in the physical world where the natural tendency is to spread out.
• How does this model help to explain the fact that when a cellophane bag of colored solution is placed in water, the color not only becomes the same inside and outside the bag, but the colored molecules do not return to the bag in their original concentration no matter how long the bag is left in the water?	Apparently events at the molecular level are governed by the same rules of chance as in the model. These exchanges are not reversible. The former idea, which is introduced here for the first time, will be developed further in Minisequence V.
• Can heat energy be "unmixed" --that is, once the temperature of the hot and cold samples have reached	No--this is contrary to the children's observation. In order to return the system to its original conditions, one

TEACHING SEQUENCE	COMMENTARY
equilibrium, is the heat energy ever transferred back into the hotter sample by itself?	would have to separate the cups, add heat energy to one, and remove it from the other. In other words, the intervention of an outside agent is required together with an external energy source. By itself, the natural tendency is for heat energy, also, to spread out in one direction. In the next two Activities the children will observe how these unidirectional transfers of matter and energy take place.

EXTENDED EXPERIENCE:

Some of the children may wish to try different numbers of beans in the two cups. For example, they might put twenty white and twenty blue beans in cup 1 as before, but eighty white beans in the other cup. Try to have more than one trial made so that the results can be compared and averaged.

This experiment shows that the final, "equilibrium" distribution approaches equal concentrations in the two cups, i.e., about 7 blue out of 40 in cup 1 and 13 blue out of 80 in cup 2. Note that the number of blue beans does not become the same in both cups, but the concentration or percentage of blue beans does become nearly the same. This is analogous to the way in which heat transfer stopped when temperatures became equal in the two samples in Activity 3, whether or not the actual numbers of h.e.u. were the same.

Activity 6 Transfer Along a Line of Cups

The children begin this Activity by observing an experimental situation analogous to that of the model in the previous Activity: two cups, one which contains blue food color and the other which contains clear water. Asked to predict, on the basis of the model, what will happen when spoonfuls of liquid are exchanged between the two cups, the children suggest that the color will eventually even out between them. A more complicated situation is then introduced: what will happen if, instead of two cups, there are five cups, one containing color and the others only clear water? The children find that here also the color eventually becomes equal throughout. In the process, however, the children observe an intermediate stage in which a gradation of color develops from the most intense color in the first cup to the least intense in the last cup. This color gradient is seen to be the result of the gradual spread of the colored material down the line from regions of higher concentration to those of lesser concentration. In the next Activity the children will observe a temperature gradient, which develops as heat energy is transferred along a nail.

MATERIALS AND EQUIPMENT:

1	container of at least 4 liter (1 gallon) capacity, or 4 quart (1-liter) containers
	additional containers for clear water, if necessary (See Preparation for Teaching)
1	bottle of blue food coloring (1 tsp required)
15	cups or glasses, transparent, same as those used in Activity 5
1	large spoon, about one tablespoon size

For each team of two:

5	cups or glasses, transparent
1	large spoon, about one tablespoon size
2	blue pencils
2	Worksheets IV-4

PREPARATION FOR TEACHING:

Make up three liters (three quarts) of blue colored water using 1/4 teaspoon of coloring per liter. Put this in a large container or several smaller containers. If there is no source of water in the classroom, you will need to set up additional containers of clear water--four times as much clear water as colored water will be needed.

Set up a row of five cups ahead of time and fill them as the children will be doing in Section 2. Make a series of exchanges described there using the same size spoon they will be using, until there is a pronounced gradation in color from the first to the fifth cup. Take note of the number of series of exchanges necessary to arrive at this optimum color "gradient"--it will probably be about 20 series of exchanges. Place this set of cups aside where the children will not see them until it is time for a discussion of their results.

ALLOCATION OF TIME:

No more than 1 to 1-1/2 hours will be needed to complete this Activity.

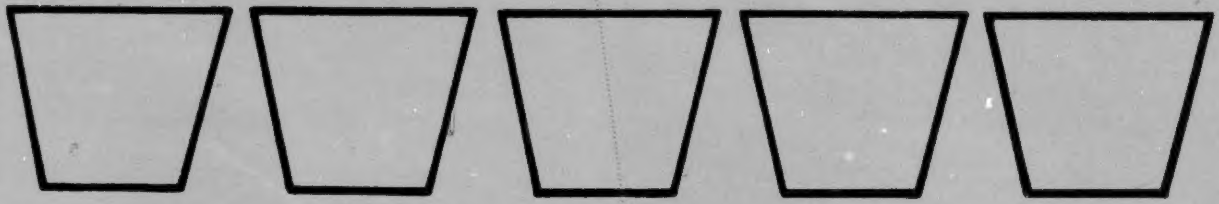
TEACHING SEQUENCE	COMMENTARY
1. Put about 1/2 cup of blue colored water into one transparent cup and the same amount of plain water into another.	The actual amount of colored water will depend on the size of the plastic cups. They should be about three quarters full.
Without actually transferring any liquid, show how you could take a spoonful of colored water from the first cup, add it to the second and stir. Then show how you could take a spoonful of liquid from the second cup, add it to the first and stir. Again, do not transfer any liquid, merely show how it is to be done.	Be sure that all the children can see what you are doing.
• What do you think you will observe when the liquids are actually mixed in this way?	

TEACHING SEQUENCE	COMMENTARY
Ask the children to predict in as much detail as they can what will happen to the coloring of the two cups of water as the spooning process is continued. For example, do they predict that the coloring of the second cup will eventually equal that of the first? Do they think all of the coloring will eventually end up in the second cup?	Based on the model they developed in the preceding Activity, the children should predict that the color would eventually even out. See if they do. This procedure is exactly analogous to the bean exchange. For these questions and for any others that may come up, have the children take note of their predictions for later checking with the results of the actual experiment.
Next, proceed to carry out the series of exchanges, using the spoon and stirring after each transfer. After you have performed the experiment, ask how the results compare with their predictions.	The water in the clear cup becomes blue, quickly at first and then more slowly as the exchange of spoonfuls of water goes on. Eventually, the two cups reach nearly the same shade of blue and no more change is seen. In other words, exactly the same thing happens as with the chance exchanges of beans in the model.
• Was the blue coloring going only from the darker to the lighter solution?	The children should realize that some blue coloring was also carried back in each spoonful that was transferred from the lighter colored water to the darker. At first this was very little. As the two cups approached the same color, the amount of blue transferred was about the same in both directions.
Finally ask what the children think would happen to the colors of the two cups if the spooning process were continued for a very long time.	The children should be able to predict that both cups would remain about equally blue. Neither cup would become clear again. If a few of them wish to try this out and report to the class later, they should be encouraged to do so.
Now ask what they expect to happen if instead of two cups, the system consists of five	At this point, discard the contents of the two cups, rinse them, and set up a line

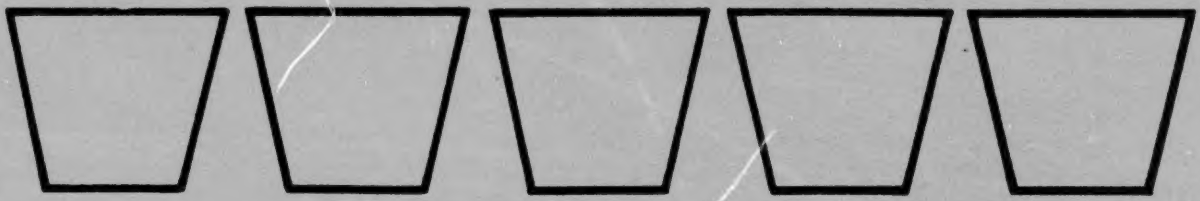
TEACHING SEQUENCE	COMMENTARY
cups. Demonstrate one exchange down the five-cup system: Take a spoonful of colored water from the first cup, stir it into the second and then take a spoonful from the second cup and stir it back into the first. Now go on to the second cup. Take a spoonful and place it in cup 3. Stir. Then take a spoonful from cup 3 and place it in cup 2 and stir. Repeat this between the third and fourth cups and between the fourth and fifth cups.	of five cups. One end cup should contain colored water while the other four contain clear water. A faint blue color will already be apparent in the second cup. With this procedure, no cup will end up "minus" a spoonful because after each transfer to the next cup, a spoonful is returned. Be sure the children see just what you do so that they can repeat this process themselves.
Ask what the children expect to observe as the interchange process is repeated many, many times. Let them suggest any questions they may have that they will be able to answer when they try it themselves. Also, let them make any appropriate predictions in response to questions which are suggested.	The children will probably predict that the color will spread down the row of cups. They may phrase it this way: "the color will get all mixed up." For example, a child may ask how many of the interchanges, such as you demonstrated, will be needed before blue coloring begins to appear in the fifth cup. Another child might ask whether the fifth cup will ever be bluer than the first.
2. Working in teams of two, as before, the children should obtain 1 spoon and five cups. Show them the supplies of blue and clear water and let them proceed to set up the experiment.	The 5 transparent cups should be identical, of course, and they should all be about three-quarters full.
Before they start to make the exchanges, distribute Worksheet IV-4 and the blue colored pencils. Ask the children to color in the top row of cups to represent what they observe initially.	
Tell them that you would like them to color in the second row of outlined cups after	

WORKSHEET IV-4 Name:

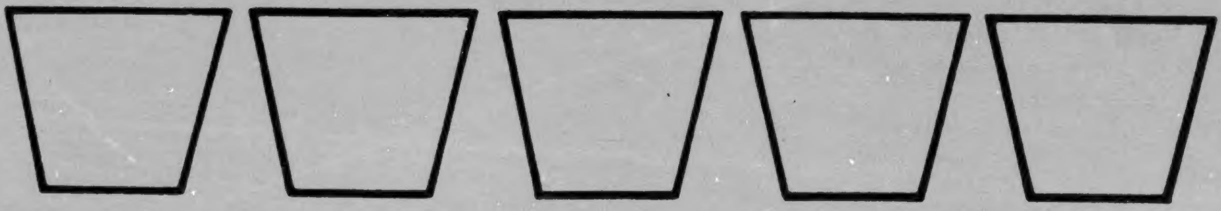
START:



AFTER ____ SERIES OF EXCHANGES:



FINISH:



TEACHING SEQUENCE	COMMENTARY
they have made 20 series of exchanges (gone 20 times down the row of 5 cups spooning back and forth). They are to use the bottom row of outlined cups to record the color of the cups at the end of the experiment.	If you find, as a result of trying this out ahead of time with the equipment the children will be using, that 20 series of exchanges is not sufficient to reach the point at which the gradation in color will be most pronounced, tell the children to color in the second row after the number of series of exchanges that you have found will yield the desired gradation. The size of the cups or glasses, the volume of contained liquid and the size of the spoon used can all affect the point at which the gradient is most obvious. After that, the color will even out more and more until there is no perceptible difference between the color of the liquid in the cups.
While the children are working, set up a row of five cups with colored water in the first and clear water in the rest. Set up another row of five cups, showing the result of many series of exchanges, in which the color is evenly distributed throughout all five cups.	You may have a few children help you to prepare these sets of cups. The purpose is to give the children a visual record of color changes that occured, for use in discussion.
Ask whether everyone observed a progression as shown by the sets of cups you have prepared. Which set is like the set they began with? Which set did theirs resemble after many, many exchanges?	The children should all have observed a regular progression from the initial situation with all the color in one cup toward the equilibrium situation with the color evenly divided among the five cups.
• What did you observe in the cups after 20 series of exchanges? Bring out the row of cups showing the color gradient.	There should be general agreement that between the initial situation and the equilibrium situation there was a gradation in color from most intense in cup 1 to least intense in cup 5.

TEACHING SEQUENCE	COMMENTARY
• How would you explain this color gradient? How did it develop?	In the previous Activity the children observed the transfer of blue beans into a cup of white beans just by chance picking. Here, they could actually observe that a spoonful of liquid transferred down the gradient contained more of the color than did a spoonful transferred the opposite way. (If the children did not observe this you may wish to have a few new setups prepared so that the children can pay close attention to the transfer of color.) Again, the net flow is from the region of higher concentration to that of lower concentration.
• Do you think such a gradient of color existed during the time when the blue food color was moving out of the cellophane bag into the clear water outside?	Yes--but it would have been difficult to see. However, some children may have noticed that the color appeared outside the bag first nearest the bag wall and then gradually moved farther out into the clear water. The beauty of this setup is that the contents of the four cups which contained clear water originally remain separated and therefore easily observable. The children can observe the spreading out process in a kind of undisturbed slow motion. Furthermore, they can "stop the action" at a point in time during the transfer of colored particles--say, after

TEACHING SEQUENCE	COMMENTARY
	the first 20 series of exchanges--and observe the stages in the evolution of the system as it approaches equilibrium.
• Do you think the same thing happens in the case of the transfer of heat energy?	Invite speculation about this question as a transition to the next Activity. Because of other similarities between the two types of transfer, some children may predict the existence of a temperature gradient in a comparable situation.

Activity 7 Transfer Along a Nail

Earlier in this sequence the children studied the transfer of heat energy from a hot sample of water to a cooler one with which it was in physical and thermal cnntact--but not mixed. They found that heat energy spread from the hotter to the cooler sample no matter what the initial heat energy of the two samples. This transfer continued until all parts of the system were at the same temperature. In the present Activity they will observe the transfer of heat energy through a continuous medium--a long iron nail. In this setup there is no physical separation of different parts of the system. Also, it is "open" with respect to its surroundngss, as compared with the insulated double-cup system investigated previously.

The children construct an apparatus which allows them to measure the temperature along the nail in four places. Observation of the four thermometers will show a temperature gradient: If a flame is adding heat energy to one end, children will observe a gradation in temperatures down to the unheated end. They will observe an opposite temperature gradient if a piece of melting ice removes heat energy from one end. In other words, as before, they can infer that heat energy is being transferred only from higher temperature to lower temperature regions. The temperatures will even out if a heat source is applied to both ends or if all sources of heat are removed. This is analogous to what happened in the previous Activity where eventually the color evened out in the five cups.

The temperature gradient is very similar to the concentration gradient of colored molecules in the five cups. In both cases, the tendency is for material or heat energy to spread out in one direction: down the gradient, from higher concentrations to lower. The random process by which this takes place will be explored more fully in Minisequence V.

MATERIALS AND EQUIPMENT:

supply of cellophane tape

supply of aluminum foil

1 large iron nail, at least 10 cm (4 in.) long

1 piece of corrugated cardboard as described below

4 thermometers as described below

1 clock or timer with sweep second hand

supply of paper towels

For each group of 4 children:

4 thermometers, -20°C to +50°C

1 piece of corrugated cardboard, 3 in. by 7 in. (8 cm by 18 cm)

1 large iron nail, at least 4 in. (10 cm) long

scissors

1 small rubber band

2 candles, preferably the short, fat type used in Minisequence II

1 3 in. by 5 in. (8 cm by 12.5 cm) card

2 ice cubes

1 large aluminum nail, at least 4 in. (10 cm) long (optional)

1 piece of glass rod, at least 4 in. (10 cm) long, e.g., glass swizzle stick (optional)

Worksheet IV-5 (The number needed will depend on the number of experiments the children do.)

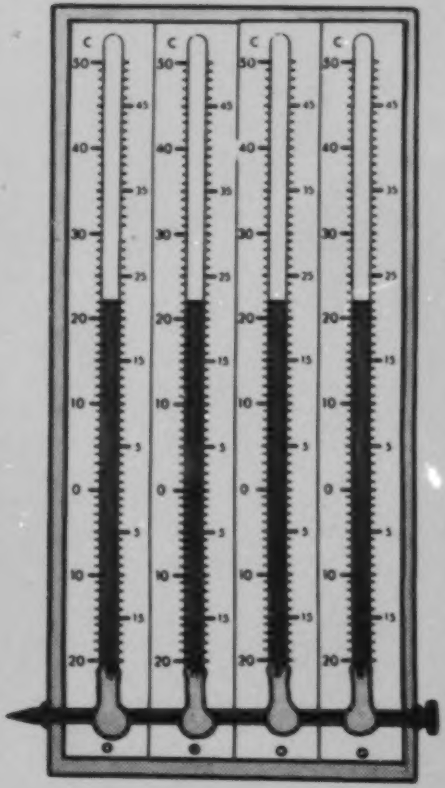
4 pieces of graph paper, 4 sq/in. (2/cm)

4 red pencils or crayons

PREPARATION FOR TEACHING:

Before teaching this Activity, prepare one heat transfer device in front of the children as described below and on page 319. This can be used as an example for the children when they construct their own.

Cut a 2-cm square of aluminum foil for each of the four thermometers. Wrap and crumble these around the bulbs of the thermometers. (If the bottom part of the plastic backing has been cut away from the thermometers as a result of their work in Activity 4 of Minisequence II, the thermometer can still be used, of course.) Cut a larger piece of aluminum foil about 20 cm by 30 cm and use it to cover completely the piece of corrugated cardboard. A little cellophane tape on the back will keep it in place.



Next, place the four thermometers side by side lengthwise on the foil-covered cardboard. Use a ruler or other straight edge to get the thermometer bulbs into a straight line. Then tape the ends of the thermometer backings to the covered cardboard.

Finally, place a nail under the thermometer bulbs. It should extend out one or two centimeters on each side of the array of thermometers. Loop a rubber band over one end, around the back, and over the other end to hold the nail in place. If necessary, move the nail slightly so that it passes directly under the bulbs of all the thermometers, as shown in the sketch.

It would save time if the pieces of corrugated cardboard were pre-cut to the necessary size. You will also need to prepare ice cubes ahead of time.

ALLOCATION OF TIME:

The children will need 1-1/2 to 2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. As you begin this Activity you might review with the children what changes in temperature they observed when they placed a cup of hot water in an insulated cup of cold water.	They should recall that the temperatures equalized. The water at the higher temperature gave up heat energy to that at the lower temperature. The end result was that the heat energy redistributed itself over the total amount of water available, just as the blue molecules did, and the temperature

TEACHING SEQUENCE	COMMENTARY
	in both parts of the system became the same.
• What do you predict would happen to the temperature of a system consisting of a nest of four cups containing cold water and one innermost cup containing hot water?	The children should expect that the hot sample would transfer heat energy to the next sample, which would get hotter and then transfer heat energy to the next, and so on down the line--as with the transfer of colored particles.
• Would the transfer of heat energy stop? If so, when?	It could be predicted that the transfer would stop when the temperature throughout the system was the same.
• If you put a thermometer in each of the cups during the heat transfer, what do you think you would observe?	Some children may sense that there would probably be a gradation in temperature from the innermost to the outermost cup; others may not.
• Suppose the outermost cup were not insulated and you had a way of keeping the water in the innermost cup at a high temperature. Would the temperature eventually become the same throughout?	Invite the children's speculation about what would happen in such a system, which is unlike any they have worked with before.
Suggest that the children find out experimentally what would happen when heat energy is applied to one end of such a system. A system consisting of several nested cups containing water and thermometers is difficult to work with, however. A less awkward setup to test their ideas can be made using thermometers and a large nail. Bring out the heat transfer device that you made ahead of time and show it to the children. As you show them the four thermometers, indicate that they can use them to measure	Some children may enjoy the challenge of trying out the above "thought-experiment" with the cups. They should be encouraged to do so, using an insulated outermost container and a sample of hot water in the innermost container. (They need not be restricted to the use of small cups.) Setting up an uninsulated system in which the innermost water is kept continuously hot is even more of a challenge. Encourage interested children to work out a way of doing so. (One solution would be to use a series of graduated Pyrex measuring

TEACHING SEQUENCE	COMMENTARY
temperatures along the iron nail with which they are in contact. Instead of having a series of cups with water, the nail is the substance to which heat energy will be added. Tell them that they will be subjecting one end to the flame of a candle.	containers with the smallest one holding water kept hot with an electric immersion coil ordinarily used to heat soup or other liquids.)
The children should notice that this device is completely open to its surroundings. There is no insulation at either end of the nail.	
• If no end has its temperature raised, what do you predict will happen to the temperature along the rest of the nail?	Intuitively they may expect the end where heat is applied to get hot, but many may expect the entire nail to get just as hot if heat energy is constantly supplied to it.
2. The children can conveniently work in groups of four for this activity. Have each group obtain 4 thermometers, a piece of corrugated cardboard, some aluminum foil, a nail, and a rubber band. Assist them in constructing similar devices to the sample setup in the manner described in the Preparation for Teaching. Have each group first cut out the pieces of aluminum foil required: four 2-cm square pieces to cover each bulb and one piece 20 x 30 cm to cover the cardboard.	The thermometers may vary somewhat from lot to lot. Those used by each team should have their bulbs in the same position with respect to the temperature markings so that they may be placed with their corresponding markings in a horizontal line when the bulbs are lined up. The thermometers should also be checked to see that their stems are not loose and that their calibrations agree. Loose stems can be secured to the backing with tape at the upper part of the stem; the calibration, or similarity in response between the four thermometers, can be checked by placing the thermometers in a foam cup of water at room temperature, stirring, and reading to see if all four register nearly the same temperatures.

TEACHING SEQUENCE

When the groups of children have completed construction of their heat transfer devices, distribute a candle to each group. Also distribute copies of Worksheet IV-5.

Discuss the Worksheets and procedures. Suggest that they first record the temperature of the thermometers in the time 0 line of spaces.

For their first experiment with this setup, they can heat the nail by placing one end near but not in the side of the candle flame. Working in teams they should be able to devise a method of reading and recording all four temperatures every half minute. Caution the children not to let the temperature of any thermometer go above 45°C. (The temperature will continue to rise even after the end of the nail is removed from the flame and if it goes above 50°C, the thermometer can break.) When any thermometer reaches 45°C, they should remove the device from the flame and continue making observations for several more minutes.

COMMENTARY

To make the candles stand up properly, you may suggest spilling a few drops of wax onto a 3 by 5 card on the table and then placing the base of the candle in the wax before it hardens. Caution the children to remove all papers from the area around the candles. Also see that any long hair or loose clothing is tied back, Remind them again, as in previous Actitities, of the precautions they must take in working with any open flame.

If the end of the nail is placed directly in the flame, the temperature of the closest thermometer will rise too rapidly.

Since they will be holding the end of the nail near part of the candle flame while they read the temperature of all four thermometers, the children must be very careful not to get their faces so close to the system as to be too near the flame.

One member of the team might be selected to count time--that is every half minute for the readings. If there is no sweep second clock in the room, you may have to be the time keeper

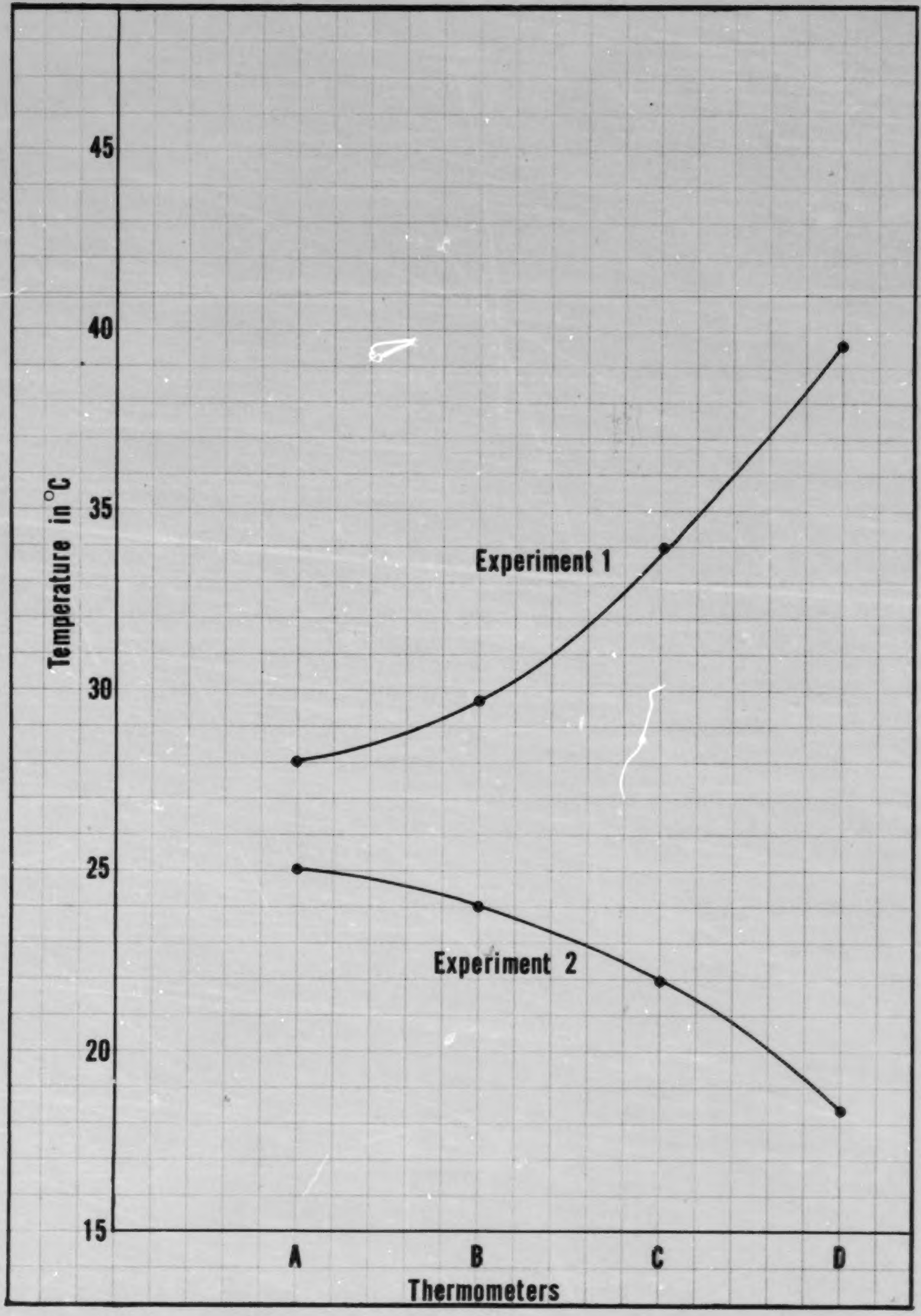
WORKSHEET IV-5 Name:

TIME (min.)	TEMPERATURE (°C)			
	Thermometer 1	Thermometer 2	Thermometer 3	Thermometer 4
0				
1/2				
1				
1-1/2				
2				
2-1/2				
3				
3-1/2				
4				
4-1/2				
5				
5-1/2				
6				
6-1/2				
7				

DESCRIPTION OF EXPERIMENT: ______________________________

TEACHING SEQUENCE	COMMENTARY
As the teams are ready to proceed with their experiments, you or an assistant can go around with a lighted candle from which the groups can light their own candles.	or have a child call out for all the groups doing the experiment.
3. After the children complete this first experiment, where heat energy was added to one end of the nail using a candle flame, have them write a brief description of what they did in the space provided on the Worksheet.	
Discuss the results of the experiment:	The children will have observed that the temperature shown by the thermometers went up as heat energy was added to the nail.
• In which thermometer did the temperature go up the most?	The one closest to the flame.
• Where was the heat for the more slowly rising thermometers coming from?	If it should happen that some children do not think the heat energy goes through the nail, do a control experiment without a nail.
• What happened to the temperature of the four thermometers after the heat source was removed?	The temperatures evened out again. If left long enough, they returned to the equilibrium condition with which they started.
• What temperature did the thermometers show after, say, two minutes?	By then, a pronounced temperature gradation should have been obvious.
Give each child a piece of graph paper and a red crayon or pencil and ask them to make a graph representing the temperatures of the four thermometers after two minutes. They should draw in the best trend line they can and identify the curve as being that of experiment 1.	Depending on which end of the nail they placed in the candle flame, the children will have a set of four dots sloping downward to the right or to the left. This is fine.

TEACHING SEQUENCE	COMMENTARY
Exhibit a graph that has been made by one of the children. Ask the class to interpret the marked points for you.	
• Which thermometer was nearest the end being heated?	The highest point on the graph will show the temperature of the thermometer nearest the end being heated.
• Which way do you think heat energy was being transferred along the nail?	Help the children to realize that the heat energy was being transferred along the nail from the hotter end to the cooler end and ultimately out into the still cooler air of the room.
Select a set of data for discussion which show a temperature above 43°C at the hot end. Referring to their experience with salol in Activity 2, ask what they might expect to happen to a piece of salol if it were placed at that end of the nail.	It should melt--its bonds would be broken by the heat energy transferred to it.
Then ask if they would expect it to melt if placed at the other end of the nail.	No, the temperature is too low.
• How could the heat energy do the job of melting at one end but not at the other?	By this time some children may recognize that the heat energy was spreading through the nail (just as it spread out in the combined water sample when a mix was made). However, here it not only spread out, but went off continuously into the air.
4. What would happen if one end of the nail had its temperature lowered? The second experiment the children might try is to place a piece of ice at one end of the nail. Distribute a fresh copy of Worksheet IV-5, an ice cube, and paper towels to each group.	Encourage the children to predict the pattern of temperatures that would develop if an ice cube were placed at one end of the nail for a few minutes and then removed, as was done with the heat source.


Temperature in °C
45
40
35
30
25
20
15
Experiment 1
Experiment 2
A
B
C
D
Thermometers

TEACHING SEQUENCE	COMMENTARY
When the children have completed this second experiment and graphed their results, questions such as the following can be used to direct and focus the subsequent discussion.	The graph for experiment 2 can be placed on the same or different set of axes. Sample results for experiments 1 and 2, in which the heat source and the ice respectively were placed nearest thermometer D, are shown on page 326.
• What happened to the ice when the end of the nail was placed on it?	The ice melted where the nail touched it.
• Where did the heat energy needed for melting come from?	It came from the nail, which was at a higher temperature (room temperature) than the ice.
• Was heat energy transferred toward or away from the ice?	Heat energy was transferred toward the ice. Again, heat energy went from higher temperature to lower temperature regions.
• Did a temperature gradient form in this case? How was it different from the one that was formed during experiment 1?	Yes--but it slopes in the opposite direction. In both experiments, however, heat energy went "down the gradient."
• Did the temperature readings on the thermometers ever even out?	The temperature readings would have equalized only after the ice cube was melted entirely or after it was removed from the nail. Gradually the gradient would reduce and the nail would return to room temperature--just as when the source of heat energy was removed.
If the children have not already drawn attention to the similarity between the color concentration gradient observed in the previous Activity and the temperature gradients observed here, draw their attention to it with a leading question. Then ask:	

TEACHING SEQUENCE	COMMENTARY
• At what point did the colors in the set of 5 cups appear similar to the temperature readings of the heated or cooled nail?	After about 20 series of exchanges, the children observed a gradation in color similar to the one that developed as heat energy was transferred along the nail.
• In what way did their five-cup system differ from the nail?	The nail was a continuous open system. Heat energy was given off to the room or absorbed from it at one end.
5. Besides the experiments described above, the children may wish to try various other combinations of heating and/or cooling one or both ends of the nail. Supply the children with additional candles or ice cubes as needed. You should also supply additional copies of the Worksheet for each experiment they try.	If two candle flames are applied to the nail--one on each end--the temperatures will eventually equalize throughout; the same thing will happen if two ice cubes are applied to either end of the nail. In the latter case, however, the temperatures would equalize at a lower level. Putting a candle flame at one end and an ice cube at the other will result in a very steep temperature gradient that will be maintained as long as the flame and ice are present.
Again, choose sample graphs and ask the class to interpret them.	With any particular set of points, they should be able to read the temperatures and tell which way the heat was flowing (always from high temperature to lower temperature). Perhaps they will also be able to make a reasonable guess for a procedure that could have been used to produce such a set of points. For example, suppose the four temperatures were 45°C, 34°C, 30°C and 42°C respectively for the four thermometers. Then the heat transfer would have been from both ends to the middle. (It could be predicted that a
Such experiments should reinforce their understanding that as long as one end of the medium (the nail) is at a different temperature than the other, and is maintained at that temperature, there will be a temperature gradient along the nail. All parts of the nail will come to the same temperature when heat energy is not being added, when there is no cooler region to which	

TEACHING SEQUENCE	COMMENTARY
heat energy is being given up, or when both ends are being maintained at the same temperature.	reading made a short time later would show higher temperatures on thermometers B and C.) One way that might have been used to achieve such a distribution of temperatures would be to add heat energy (e.g., a flame) to both ends of the nail simultaneously.
Conclude the Activity by asking the children to describe the similarity between the behavior of the blue coloring and the behavior of heat energy.	There, the concentration of coloring was related to the direction of the transfer of material; here, the concentration of heat energy (the temperature), was related to the direction of heat energy transfer. In both cases, changes in the system depend upon temperature or concentration differences, and the direction of flow is from higher to lower temperatures or concentrations. This natural tendency to spread out is apparently governed by a random process of exchanges, the nature of which will be more fully explored in the next Minisequence.

EXTENDED EXPERIENCE:

Let the children use glass rods or large aluminum nails, (at least 4 in. long) in place of the iron nails in their setups. They can investigate whether or not these materials behave any differently than the iron in experiments similar to those in the preceding Sections.

With the glass rod, the children will observe that the transfer of heat energy occurs much more slowly. Also, they should notice that the temperature differences remain large even after the end of the rod has been heated for a long time. The slow transfer of heat energy is not able to keep the far end of the rod very much above the temperature of the surroundings.

With the aluminum nail, the children will observe that the heat energy is transferred more quickly than it was with iron.

Equilibrium will also be achieved more quickly and fewer differences in temperature will be registered by the thermometers because the heat energy can be transferred so much more easily.

Minisequence V

Random Events: Order Out of Disorder

Starting in Grade 1 of COPES the children were introduced to the concept that as one makes measurements on a population of related objects or events, differences are observed. Such differences are to be expected of any population, particularly one found in nature. This concept was further pursued in Grade 3, Minisequence III, where concepts of a range in values and averaging were introduced, and again in Grade 4, Minisequence VI, where the histogram form of frequency distribution was introduced as a way of describing variability. Finally, in Grade 5, Minisequence V, the children were introduced to some elementary statistical methods for inferring results by sampling populations.

All of these Activities had as their primary objective convincing the children that variability is to be expected in nature, leading to the overall conceptual scheme, The Statistical View of Nature. While it is easy to observe variability in nature, it is not so easy to demonstrate that it is the result of randomness. That is, given two leaves from the same tree, or two offspring from the same parents (even "identical" twins), it is easy to find differences between them. How can one account for these differences? The modern view is that all of nature is basically random, in the same sense as a game of chance, and that the overall orderly appearance of natural phenomena is the statistical result of numerous random events. What this means is that while sub-microscopic phenomena are random (e.g., the behavior of individual atoms or molecules, the behavior of large numbers of such random events is predictable and orderly, on the average.

A good example is the behavior of a gas in a container. While it is impossible to say anything about the behavior of an individual structural unit (molecule) since the molecules move about in random fashion, one can, by applying statistical methods to this random motion, account for the overall properties of the gas, such as its pressure as related to its temperature and volume. For example, one can account for the fact that the volume of a gas will decrease proportionally as its pressure increases. We know that the same applies in games of chance. While we cannot predict with certainty the outcome of a single toss of a coin, or of a die, we can predict the *average* outcome of a number of tosses. Moreover, the greater the number of events (tosses), the more accurate is our prediction. Thus, we must look upon the natural phenomena that one normally comes into contact with (large scale phenomena) as really exhibiting the average behavior of large numbers of individual events--so large, in fact, that predictability becomes routine and nature appears orderly. Because most things we observe in nature fit this category, one rarely observes the randomness associated with individual events. There are some phenomena that can be observed, however, that involve so few individual events as to exhibit this random behavior.

The present Minisequence extends the children's earlier experiences in this area to several new Activities designed to show how one derives "order out of disorder." The first Activity deals with a well-known phenomenon that is a classic example of the order derived from large numbers--the diffusion of molecules in liquids. Only the net result of the motion of large numbers of molecules is observed by the children as they watch food color spread through water and gelatin, but they are led to conclude that a reasonable way to account for the observed diffusion phenomena is to assume completely random motion of the individual molecules. The next Activity strengthens this hypothesis by having the children themselves simulate this by moving about the room (like molecules), their motion being governed by the outcome of a game of chance. Thus the children take a "random walk" and find that the net effect of their overall motion resembles that of a drop of food coloring diffusing through gelatin.

Further reinforcement of this concept is provided in the third Activity, where the children take a "trip by chance." Here again, they find that the outcome of a large number of random events is orderly and predictable, whereas the result of individual events, or of small numbers of events, is unpredictable. They find that by combining their individual data, they get the equivalent of large numbers of events, namely, greater predictability.

The last two Activities deal directly with random phenomena in nature. Activity 4 offers perhaps the best example of the randomness of individual events in nature. The decay of weakly radioactive substances occurs so infrequently as to make it possible to observe the individual events. Using a Geiger counter apparatus that produces audible "clicks" (or a tape recording from such an apparatus), the children actually count the number of decays that occur in a given time interval. They find that the clicks occur at random, and that the only way they can predict the average rate of occurrence is to count over a long period of time--that is, obtain a larger sample of clicks.

The last Activity does not demonstrate randomness in the same basic sense as the previous one, but rather the result of randomness in a biological situation. Here, the children are introduced to the idea of random selection as applied to the inheritance of eye color. Working with data on the eye color of house flies over several generations, the children discover that in addition to a random process, a factor known as *dominance* also must be considered in order to predict the outcome of a large number of such events--i.e., predict the eye color of second and third generation offspring.

The concepts developed in this sequence are as follows:

1. The outcome of a random event cannot be predicted with certainty. Examples of random events include movements of individual molecules, radioactive disintegrations, camphor "walk" on water, tosses of a coin, etc.

2. The outcome of a random event is completely independent of any prior history.

3. The outcome of a series of random events may exhibit a sense of order and predictability. The larger the number of random events in the collection, the higher the degree of order and predictability.

4. Games of chance which are based on random events can be used to simulate the orderliness of collections of random events.

5. A small sample of random events will exhibit great variability as compared with a larger sized sample; order will emerge as the sample size increases.

6. The movement of individual molecules within a liquid (or gas) is viewed as random. The orderliness of a diffusing column can be thought of as the net result of the random motion of an extremely large number of individual molecules.

7. The transmission of genetic characteristics can also be viewed as a result of random or chance events.

8. As in all series of random events, the inherited characteristics of one individual cannot be predicted with any certainty; however, the distribution of such characteristics in a large collection can be predicted.

Activity 1 Diffusion Along a Tube

Molecules tend to diffuse into regions available to them, depending upon their ability to move. They mix with molecules in the air, with molecules of water, etc. When drops of a colored solution are added to water, there is a fairly rapid spread of color, aided by convection currents in the liquid. When the colored molecules are impeded by the walls of a cellophane bag, as in the previous Minisequence, the mixing is much slower. This movement of molecules, which is called *diffusion*, can be better observed by eliminating convection currents and slowing the process down still further, for instance, by allowing the molecules to move through a highly viscous medium such as gelatine. The gelatine is made with a water base--thus, water-soluble molecules can move through it.

A drop of a concentrated solution of food color, initially sitting on top of a clear gel in a test tube, will be observed after several hours to penetrate it. After a day or two, a band of color is observed. Furthermore, within the band a gradation of color can be observed. Thus, a gradient in color forms in the gel similar to the gradient in temperature along a nail. Over time this gradient extends down the tube. Questions are raised about this movement of molecules: Do they always go downward? If food color were placed on the bottom of the tube, would it stay there? The children find that molecules move from areas of higher concentration to lower, as expected, and that this movement is not affected by gravitational attraction--if they are placed on the bottom of a tube, they will eventually diffuse up to the top; if placed on the top they will diffuse down. The same is true if food color is placed in water. These molecular movements can be followed because of the distinct color of the molecules--but the conclusions can be related to the movement of any molecules.

MATERIALS AND EQUIPMENT:

1	bottle of blue food coloring, 1-oz
2-3	packets (7 g each) of unflavored gelatine
1	measuring cup, 8-oz
4-5	cups, 1-oz (approximately 30-ml), waxed paper or plastic

4 test tubes, about 18 mm by 150 mm, plus corks to fit

1 tall glass or plastic tumbler, to serve as a rack for the above test tubes

green food coloring (optional)

yellow food coloring (optional)

For each team of two children:

4 test tubes, 13 mm by 100 mm

4 corks for the test tubes

1-2 jars to serve as test tube racks

1 medicine dropper

PREPARATION FOR TEACHING:

At least a few hours before you will be conducting this lesson, dissolve one envelope of unflavored gelatine in about 100 ml (3 oz+) of hot water. Hot tap water (about 50°C) is satisfactory. Stir until the gelatine is completely dissolved. Pour this liquid into two large test tubes, filling each about 2/3 full. Allow the gelatine to solidify for a few hours before beginning this Activity. Also, fill two similar test tubes to the same level with plain water. They should be corked to prevent drying until just before they are used. Place all the tubes in a tall drinking glass or plastic tumbler.

Just before you begin, set out the supplies the teams will need: the small test tubes, corks, medicine droppers, and jars to serve as test tube racks. If the children are to make their own gelatine, they will need a source of hot water. You may wish to make the gelatine and fill all the tubes which the class will need ahead of time, so that the gelatine will be set by the time the children are ready to work with it (see the directions on page 337). When the teams are ready to take their food color, put out a small supply in the 1-oz cups at convenient stations throughout the room.

ALLOCATION OF TIME:

The children will need only about 1-1/2 hours to complete this Activity. However, the observations are spread over several days.

TEACHING SEQUENCE	COMMENTARY
1. Put out the four large test tubes (2 with water, 2 with gelatine) for the children to see. Show them the bottle or container of blue food coloring and ask:	
• What do you predict will happen if I add a drop or two of the blue food color to the liquid in the test tubes?	After their experiences in Minisequence IV, they should readily predict that the blue color will spread out in the liquid. Note that in this Activity the food color is used in its concentrated form as it comes from the bottle. It is not diluted with additional water.
Without letting on that some of the test tubes contain gelatine, take some blue food coloring in an eye dropper, pick up one of the test tubes of water and, while the children watch, add one drop of blue food coloring to it. Let them observe and describe what happens. Repeat with the other tube of water and let the children pass the tubes around, examine and discuss them.	Try not to jiggle the test tubes. If you do, the children might notice the difference between the ones with water and the ones with gelatine. You may want to hold the tubes so that the surface of the water or gelatine is hidden with your fingers.
Ask the children to watch as you try it one more time. This time choose one of the tubes of gelatine.	When you put the drop of food coloring in this tube, it will remain on the surface of the gelatine. This should elicit exclamations of surprise.
When the children ask, you should admit that the tube does not hold plain water. Rather, it contains gelatine and water. Pass the two gelatine tubes around for the children to examine more closely.	

TEACHING SEQUENCE	COMMENTARY
• What do you think might happen to this drop of blue food color over time?	They have not investigated this system before but their previous experience with food coloring might lead some to expect it to permeate the gelatine.
Working in teams of two, the children can now set up their own food color and gelatine systems so they can observe the properties over a period of time.	
With the help of a few of the children, make up the gelatine solution (if you have not already done so).	Each team will need about 10 ml of gelatine, 5 ml for each test tube. The gelatine comes in 7-g packages, each of which is to be dissolved in 100 ml (slightly more than 3 oz) of hot (50°C) water, as described in the Preparation for Teaching. Thus, 10 teams can be accommodated by one package. It would be best to make up the solution in a measuring cup with a pouring spout so that the children can fill their test tubes easily. After all the test tubes are filled with gelatine, put the remainder in some extra tubes which can be used later for any Extended Experiences.
Each team should obtain four test tubes, four corks, a medicine dropper and a jar or two to serve as a test tube rack. They should then fill two of the test tubes about 2/3 full with the warm gelatine solution and put them aside to set after they have identified the two tubes as belonging to them.	
2. Once the gelatine is set, they can prepare the system for observations: Each team should place one	If the tubes have been prepared with gelatine ahead of time, the children will not have to wait the few hours (or until the next day) for

TEACHING SEQUENCE

drop of the blue food color on top of the gelatine in each of the two tubes.

The third and fourth tubes should first be filled to about the same depth with water. They can use one of them to reconfirm how the color behaves in water. Have them add one drop to one of the tubes and describe what happens.

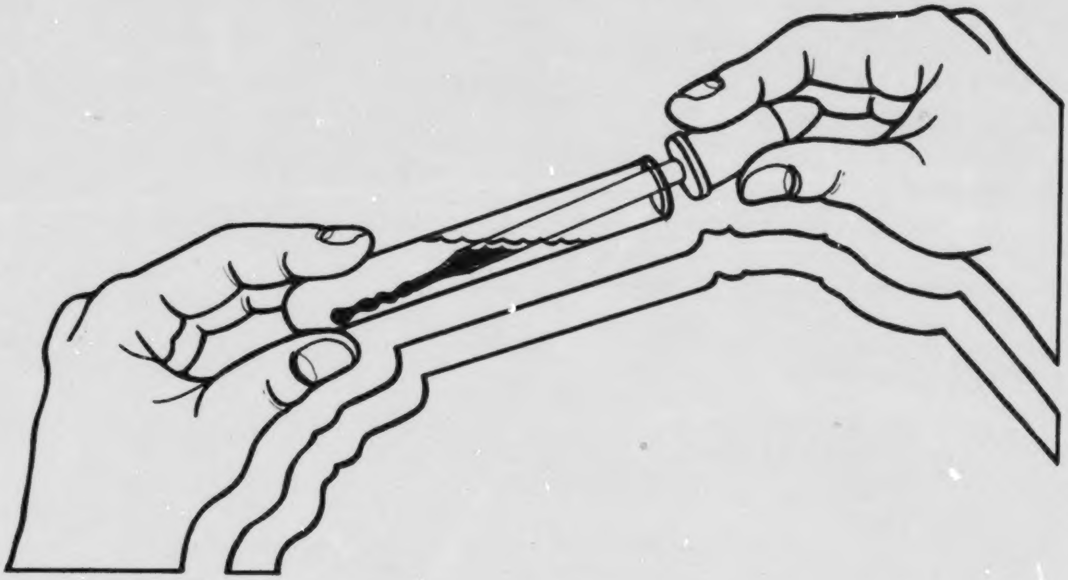
- Will the color always go to the bottom? What would happen if it were put at the bottom to begin with?

COMMENTARY

the gelatine to set before proceeding.

Again, the drop will remain on the surface.

In most instances the color will tend to swirl down towards the bottom of the tube. They should try not to agitate the contents.



Have them tilt the second tube of water a bit, then--without squeezing the bulb--insert the dropper which

TEACHING SEQUENCE	COMMENTARY
contains some of the concentrated blue coloring into the water as far as it can go. Then release one drop of the color so it runs down to the bottom of the tube.	You might wish to demonstrate the technique to them.
Set the tube upright and observe the drop.	There will be some residual blue coloration in the upper part of the test tube but most will be settled on the bottom. Again, they should try not to agitate the contents.
The children should now have two tubes with gelatine, both with a drop of blue food coloring on top, plus two tubes of water, one with most of the blue coloring at the top (test tube 3) and the other with most at the bottom (test tube 4).	
• What do you predict will happen to the four systems over a period of a few days?	Some children, seeing the blue color settling to the bottom, may predict that all the color will eventually go to the bottom. Others may predict that the blue colored molecules will become evenly mixed with the water.
They should cork the tubes and set them aside where they will not be disturbed but where they can observe them occasionally to check their predictions.	If mold growth should appear in a gelatine tube at any time, remove it and wash the tube with hot water.
3. Over a period of days the teams should make (and record) their observations of the test tubes.	It will be apparent within a few days that the blue color is not going to settle to the bottom of test tube 3. By the next day, the blue will appear to be completely mixed with the water. By then, the children should also notice an interesting phenomenon in the gelatine tubes: The blue coloring will be seen to be gradually moving

TEACHING SEQUENCE	COMMENTARY
	into the gelatine. There will appear to be a gradient of color concentration from dark blue to light blue in a section at the top of the tube.
Ask the children to describe the phenomena in the gelatine tubes.	
• In which direction are the blue molecules moving? Why?	Down the tube. Some children may suggest that gravitational attraction is pulling the blue molecules downward.
When the suggestion is made that weight, or the attraction of gravity, accounts for the movement of the blue molecules, some children (or you, if necessary) may question it. Then have each team take one of the tubes containing gelatine and the drop of blue food color, be sure the cork is tight, and turn it upside down. Set the tube alongside the upright one and continue observations.	Some teams might try laying the test tube on its side.
• Will the blue molecules move up in the tube and continue to spread into the gelatine or will they sink back down towards the cork?	
4. After another five days, have the teams observe and report their findings. Refer to the phenomena they observe as the *diffusion* of the blue molecules into the gelatine and water. • Does the diffusion of color seem to be affected by gravity?	Observation of the two tubes with the gelatine will show a steady spreading of the blue molecules into the gelatine whether from above or from below. They will also have observed that in the tubes with water, all the blue color appears entirely distributed even from the pool below. In other words, gravitational attraction does not seem to affect the movement.
Eventually some children should suggest that this process is similar to that	With time, there will be an

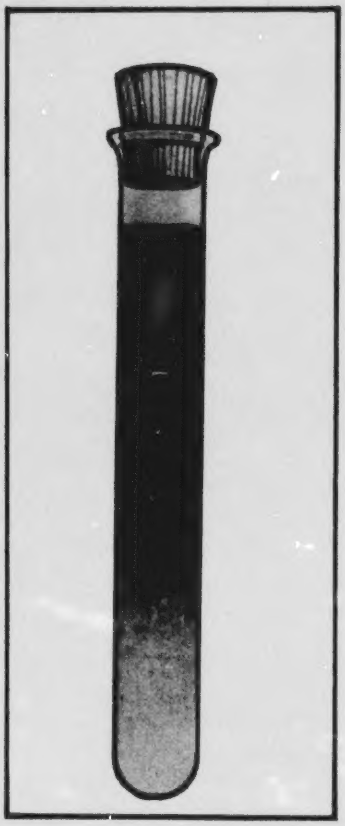
TEACHING SEQUENCE

observed in activities in the previous sequence. As before, the movement is from regions of higher concentration to regions of lower concentration. The color tends to spread out.

- How does this compare with the temperatures you measured along the nail while

COMMENTARY

even broader color gradient as the blue molecules continue to diffuse into the gelatine. The illustration below shows the gradient after a few weeks.



Some children may suggest that mixing of blue particles and water particles is going on within the gelatine and that, as before, this leads to a net transfer of molecules down the concentration gradient. Eventually, of course, there should be complete, even mixing of the color within the gelatine but this may take many weeks.

Again there was a gradient in temperatures. From the temperatures measured it could be

TEACHING SEQUENCE	COMMENTARY
heat energy was being added to one end?	inferred that heat energy was being gradually transferred along the nail.
Why do you think there was such a difference in how fast the blue molecules could diffuse through water as compared with gelatine?	Open this up for their discussion. Some children may compare this with the difference noted when a glass rod was substituted for the nail. Heat energy could not be transferred as readily. Some may recognize the difference as due to the higher viscosity (resistance to flow), "thickness," or "solid-like" nature of the gelatine.
Do you think that such an orderly color gradient could be formed as a result of chance movements of molecules?	Encourage the children's speculations. Some of them may recall the five cups but they may say that what formed there was the result of exchanges which were not "blind" as in the case of the bean model. In the next Activity, the children will begin to consider how chance, or random, molecular movements could produce the phenomena associated with diffusion.

EXTENDED EXPERIENCES:

1. Molecules of yellow food coloring move much more rapidly through gelatine than blue. Green food coloring contains both the blue and the yellow. Thus, it is interesting to mix one drop of yellow coloring with one drop of blue, place this mixture on some set gelatine in a tube, and then compare what happens there with what happens when a drop of green food color is placed on a second tube of gelatine. As the molecules diffuse into the gelatine, the yellow will appear first--even the yellow component from the bottle of green food coloring.

2. If the children appear fascinated with these observations, they might prepare some gelatine in a transparent dish to set. Then they can place small drops of different food colorings on the surface. Observing it from above will show rings of lighter color around the drops as the molecules diffuse away from the center of the drops and into the clear gelatine. Where two different colored molecules meet, the mixture will appear as the combination of the two colors. For instance, as the molecules from a drop of yellow and of blue reach the same region, the color will appear green.

Activity 2 Random Walks

Series of events have some characteristics which are orderly and predictable and some which are not. Those characteristics dealing with patterns of results are predictable; the specific outcome of a single event or series of events is, in general, not so. For instance, when tiny specks of camphor, about the size of the head of a pin, are placed in a container of water, each speck will exhibit chaotic, disordered movement on the surface of the water. An observer cannot predict which way the individual particles will move. However, although the pieces of camphor are grossly larger than any individual molecules--of camphor itself, of water, of the food color, or any substance--their behavior on the surface of the liquid portrays the kind of movements believed to take place at the molecular level in the liquid.

In the previous Activity the children observed the slow diffusion or spreading of blue color through the gelatin medium. How can this apparently orderly movement of colored particles, or molecules, result from chaotic individual movements? In the present Activity, the children engage in a game with spinners. Because their movements away from the starting position are determined only by the chance result of a spin, they are identified as random moves. These individual random moves can occur, within the constraints set up, in only two directions. Even so, although the individual moves are unpredictable, the overall shift of the members of the class is away from the starting position, the numbers of children at each position gradually decreasing. Thus the result appears as a gradient in numbers of children at each position. This gradient has been produced only by the random, chaotic movement dictated by a chance spin for each child. The model created is then related to the observed phenomena of diffusion into the gelatin. As an outcome of this, they are led to the inference that blue molecules in food coloring may also be moving in such a random fashion, the overall effect of the many molecules being that of a general trend to spread into the gelatin.

MATERIALS AND EQUIPMENT:

1 camphor cake*

1 hammer or other heavy object

1 large open pan; for instance, a pie pan

1 dish of marbles, representing a liquid, like that used in Minisequence II, Activity 3

petri dishes (optional)

plastic wrap (optional)

felt marking pens (optional)

For each pair of children:

4 pieces of corrugated cardboard, about 6-in. square

2 nails, 1-in. (2.5 cm)

2 bobby pins

cellophane tape

1 small piece of heavy colored paper or plastic

1 pair scissors

1 box colored pencils

2 Worksheets V-1

1 Worksheet V-2

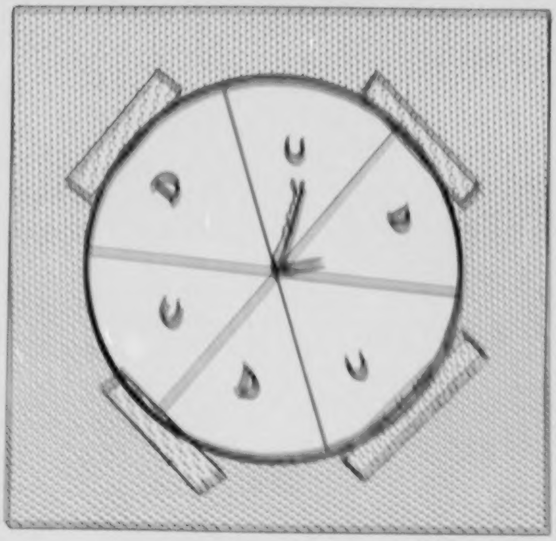
2 sheets of graph paper, 4 sq/in. (or 2/cm)

*Be sure this is the chemical, camphor, and not what is commonly referred to as "camphor" balls used for moth protection. The latter is naphthalene. Cakes of camphor are usually available in drugstores.

PREPARATION FOR TEACHING:

Using a hammer or other heavy object, crush a small piece of the camphor between two pieces of paper when you are ready to begin the Activity. Half fill the pan with water.

Construct at least one spinner to be used as a model when the children make their own. Begin by taping two pieces of corrugated cardboard together to make a piece of double thickness and about 6 in. (15 cm) square. Cut out one of the Worksheet V-1 circles and mark the sectors U (for up) and D (for down) alternately, as shown in the illustration on page 345. Tape the edges in several places so that the circle lies flat on the cardboard. Push a 1-in. (2.5-cm) nail straight through the middle of the circle and the cardboard block. Then remove the nail and push it through from the other side so that the



point is on the same side as the circle face. Use a piece of tape over the head of the nail on the back of the cardboard to hold it in place. Put a bobby pin over the nail and the spinner is ready for use. Basically, it is exactly like the one used in Minisequence VI of Grade 4.

ALLOCATION OF TIME:

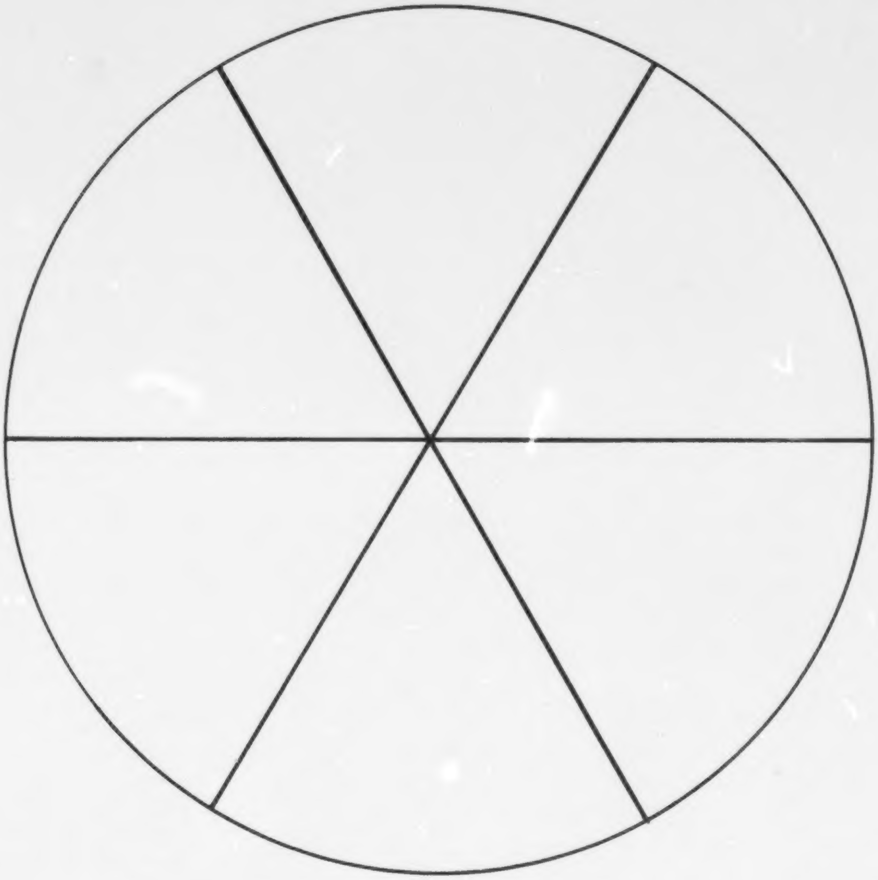
This Activity can be completed in 2 to 3 hours.

TEACHING SEQUENCE	COMMENTARY
1. Begin a discussion with examples of "can't tell" behavior with which the children are familiar. For instance, where is a fly likely to move? Which way will a pebble bounce when you drop it? Can you tell which way a man walking will turn at a corner? Then ask about a series of events, such as a child in a toy store: if the child took 50 steps, in how many different places could he or she end up?	These examples should be from the children's experiences. There is no specific answer to the last question, as it would depend on the size of steps, the arrangement of display counters, and probably other variables.
Show the children the pie pan of water. Sprinkle a few specks of camphor on the surface of the water.	The chaotic movement of the light camphor particles results from their gradually dissolving and reducing the surface tension of the water where the solution forms. The particles then move in the direction of least

TEACHING SEQUENCE	COMMENTARY
	resistance. Thus, fresh water should be used each time you wish to observe this phenomenon.
• What do you observe? Could you predict the path of one of the tiny bits of camphor?	The skittering motion of camphor on water is a good example of unpredictable movement.
Bring out the dish of marbles and remind the children of its use as a model representing molecules in a liquid. Tilt the dish so that the marbles move about freely.	See Minisequence II, Activity 3 and Activity 2 of Minisequence V in Grade 4.
• Could you predict the path of any one of the marbles?	No.
• The food color clearly progressed in an orderly fashion into the gelatine. If the individual particles of food color are moving in such a chaotic fashion in the liquid, how is such orderly progress possible?	This is a key question that should be raised here even though no definitive answers are expected at this stage. It would certainly seem that if it is equally likely for a particle to move backward as it is for it to move forward, little or no progress would be made.
Ask how you might find out some answers to the questions just discussed. Help them come up with the idea that perhaps they could construct a series of moves based on chance, and record what happens. For convenience and to simplify matters, suggest that the moves be the same size, and in only two directions as a start.	
Draw a vertical number line from -2 to +2 on the chalkboard. Put a red dot at 0 position on the number line and tell the children that the dot marks the position of a person about to take a walk in a series of moves, or steps.	They should be familiar with the "number line" concept from arithmetic, so moving away from a center point by increments should seem natural. Of course, the number lines with which they are probably familiar are horizontal. The steps being taken here are either up or down with respect to a center point, as on a

TEACHING SEQUENCE	COMMENTARY
	thermometer. However, the principle is the same. A vertical orientation has been chosen in order to make the analogy later with the movement of food color particles in the test tube of gelatine.
• What could be used to determine at random whether the person goes up or down at each step?	They will need something to specify at random, objectively, in which direction they should move. The familiar spinner, with two (or any even number) of segments would do very well. In this case they could also toss a coin to determine the direction of movement--heads, up; tails, down. However, the spinner is used because later they will want more than two determinants of action.
Give each pair of children two nails, two bobby pins, four pieces of corrugated cardboard and two copies of the sectored circle on Worksheet V-1. Also provide them with cellophane tape. Help them to construct their own spinners in the manner described under Preparation for Teaching.	Each child should construct a spinner.
When the children have constructed their spinners, show them how to flick the bobby pin. They should agree on a strategy to follow when it stops between sections. For instance, the section where the longer end lands might be the one to count.	When used, the spinner should be placed on a horizontal surface. If it is placed at an angle, the weight of the pin will favor the lower sectors. Many children may be familiar with spinners because of their use in children's games and in Minisequence VI of Grade 4.
Ask a child to spin his or her spinner and tell you how to move (not where to go!) on the chalkboard diagram. Mark X on the +1 or -1, as directed. Then ask another child to spin and tell, and	If the first move is U (up) to +1, the second may be D (down) to 0 or U to +2. If

WORKSHEET V-1



TEACHING SEQUENCE

move accordingly again.

- How could we keep track of the person's progress, if any, away from the starting position?

2. Distribute Worksheet V-2. Point out that on the Worksheet there are two rows of boxes corresponding to the number line. The children can use heavy colored paper (or plastic) and scissors to make the markers. They should have one marker to represent the moving individual, one to show upward progress and one to show downward progress. The X, or other indicator letter for the individual, moves each step as directed by the spinner along one row of boxes. The U and D move out only, never in, and show in the second row of boxes how far away from home base (0) the walk went.

Help the children get started on their walks, and tell them to stop after they have taken ten steps. They should tally each step as they take it.

After the first ten steps, be sure that the children have maintained the right records. Then have them continue to record for 20 more steps, stopping after 30 steps.

Discuss the following

COMMENTARY

it is D to 0, move and raise the question of how you can remember how far up you have gone. The children should see that a U marker is needed to show total upward progress. If the second move is U to +2, you can also raise the question because the third move may be down. If the first move is D to -1, develop a similar reason for a D marker to indicate the maximum downward movement.

Small squares that will fit on the boxes can simply be cut out. Actually any small markable object can be used.

With two rows of boxes, the U and D markers will not interfere with the movement of X.

The children may work in pairs, one spinning and the other "walking" and recording; they can switch after each set of ten steps.

If you wish, they can go on to 50 steps.

You might collect data on the

WORKSHEET V-2

Names:

		15
		14
		13
		12
		11
		10
		9
		8
		7
		6
		5
		4
		3
		2
		1
		0
		-1
		-2
		-3
		-4
		-5
		-6
		-7
		-8
		-9
		-10
		-11
		-12
		-13
		-14
		-15

RECORD AND TALLY:

	Space Occupied by			Spread Between U and D
	M	U	D	
After 10 Steps				
20				
30				
40				
50				

CONCLUSIONS:

TEACHING SEQUENCE

questions:

- What seems to be happening to the X marker?
- What is happening to the spread between U and D? Why should this be?

The children should reach these conclusions before proceeding to the next Section of the Activity:

a) The position of any person's X at a given moment is unpredictable.

b) The average position of all the X's is predictable.

c) The spread between U and D increases as the number of steps increases--in short, there is "progress" as a result of random motion.

They can record these conclusions on their Worksheets.

3. At this point return to a consideration of the movement of food color into the gelatine. Initiate a discussion of what was happening as the blue molecules diffused into the gelatine.

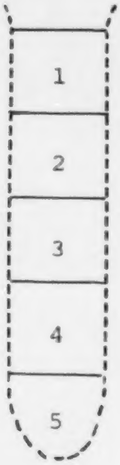
- Do you think that the blue molecules moved in only one direction?

Ask the children what they think about the possibility of molecules moving in the opposite way.

COMMENTARY

10th and 30th steps and, on the chalkboard, show the average position of X (average for the class), and the average positions for U and D.

If children respond in the affirmative, agree with that part of the response that the overall effect was to see blue color move from higher to lower regions of concentration.

TEACHING SEQUENCE	COMMENTARY
- Could the blue molecules move in either direction through the cellophane walls earlier?	Yes. The blue molecules seemed to move into the clear water whether from inside the bag or from outside the bag.
- How did the blue color move in the test tube of gelatine?	Their observations led them to infer that the blue color spread into the gel either down or up the test uube.
Suggest that they try to see if a model can be devised, based on the random motion of many individuals, which will look like the diffusion system they have observed in the gelatine. Draw six horizontal lines on the chalkboard about 15 cm (6 in.) apart, as shown in the sketch. Letter the spaces between the lines from 1 to 5.	
	If you wish, you can draw the outline of a test tube around the spaces.
- Suppose we use an X to represent a molecule of food color placed on the gelatine. In what space could the X be placed to represent its position at the beginning of the experiment?	Of course, any letter can be used to represent the food color molecules. The X could be placed in the uppermost space, 1, because the food color was placed on top of the gelatine to begin with. It spread out from there.

TEACHING SEQUENCE	COMMENTARY
Put an X in space 1 on the chalkboard. Again the spinner can be used to determine, by chance, which direction the X will move in.	
• Did the food color move rapidly or slowly through the gelatine?	There should be general agreement that the color moved very slowly through the gelatine.
To make their model conform to their observation that the food color moved very slowly through the gelatine, the children could change their spinners: they could color in four of the six sectors on the spinners, leaving only one U sector and one D sector. If the spinner lands in a darkened sector, the molecule will stay where it is. This way there will be no movement at all over half the time, slowing the process down considerably.	
Call on one child to flick the bobby pin on his or her spinner and tell the sector on which it lands. If it points to a D, erase the X and put an X in the next space, 2. If it points to a U, ask the children what should be done with the X. If any other sector comes up, leave the X where it is and ask another child to spin another number. Once the X is in spaces 2, 3, 4, or 5, it is also possible for it to move up one space. Do this whenever U comes up on the spinner.	Try to elicit the idea that in this particular case, where upward movement is indicated when the X is in space 1, the X must be left where it is because the particle of food color could not move up off the gelatine into the air.
Continue having the children spin and call out landings while you move the X until they understand the rules for moving: it stays where it is	You may need to move the X to

TEACHING SEQUENCE

when the spinner lands on the four darkened sectors. For a D, it moves down one space unless it is in space 5, in which case it also stays where it is because there is no place to move. For a U, it moves up one space, unless it happens to be in space 1, (as at the beginning), in which case it stays where it is.

Before the children begin this activity, one more key question must be raised, if the children have not already done so: Is a single X a good representation of the situation where food color was placed on gelatine?

- If you had 30 X's, say, would they all land on the 5 after many moves? Would they all come back? What do you think will happen to many "molecules" when a series of spins directs each one?

Invite them to try this out with each child's spinner directing the moves. This time, the children themselves will do the moving, or "walking," instead of a marker.

Use chalk to mark off a large area of the classroom floor into five spaces. Label these 1, 2, 3, 4, and 5, as the chalkboard sketch was labeled. Each area should be large enough that the entire group can stand in one of the numbered spaces.

Have the children begin all

COMMENTARY

space 5 and ask about the rules at that point. It probably will not get to space 5 unless the sequence is continued well beyond twenty spins. You may also need to do similar things to explain the rule that it stays if a U comes up when it is in space 1. A limited sequence of spins may not take the X against either edge.

The children should realize that representing the movement of only one molecule is unrealistic. Presumably there are many, many molecules in a drop of food color.

Encourage their ideas.

It would be best if the area could be between two actual walls which would form the outside edges of spaces 1 and 5. Otherwise make artificial walls with rows of tables or desks. Alternatively, you may find it easier to take the group outside onto a markable play surface for this activity.

TEACHING SEQUENCE

standing in space 1, as if they were several food color molecules on the surface of the gelatine. Tell them that they are each to move according to the rules developed for the X on the chalkboard. Each child should spin his or her spinner just five times and move according to the sectors that come up.

After the five spins, have the children help you count the number of people in each space. Record the results. Continue with sets of five spins until a total of twenty spins have been made.

4. Let the children discuss what they observed during the above experience. Could each of them tell where they were going to move before they spun the spinner?

Was there any pattern in the way the class as a whole moved?

COMMENTARY

You may need to remind the children to hold the spinners level to insure that all six sectors are equally likely.

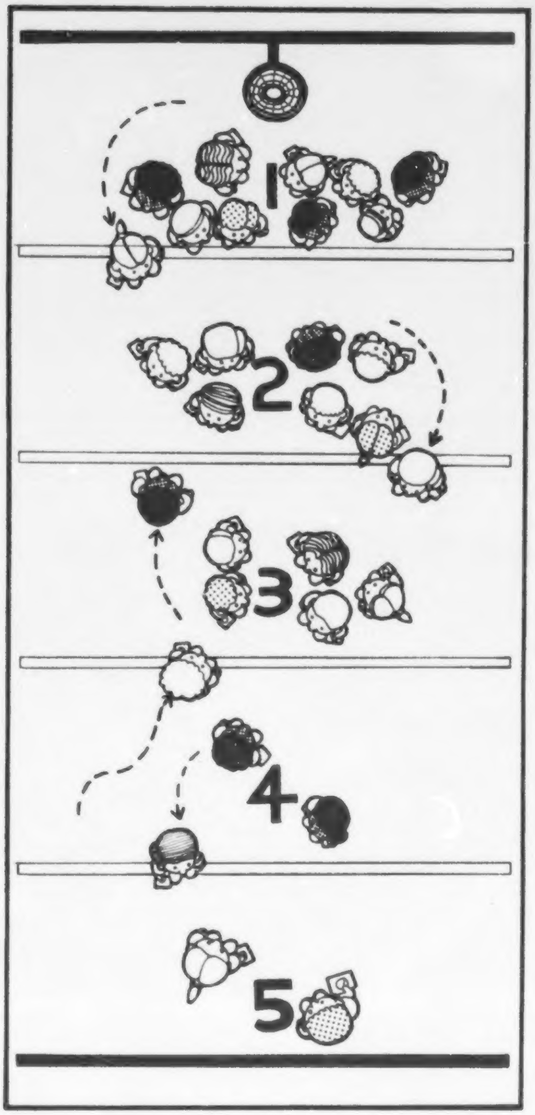
Below is a chart of typical results from this part of the activity. Your actual results will no doubt differ somewhat.

		Number of Spins				
		0	5	10	12	20
Number of Children in Space	1	30	24	13	9	10
	2		5	11	11	8
	3		1	5	5	5
	4			1	4	3
	5				1	4

No, it was unpredictable.

You can point out here the data recorded on the chalkboard. If the children wish, you may repeat the experiment to produce more data and to let the children observe the movement of the group while they know what to watch for. The children should see that they were initially concentrated in one place, but that the different chance movements produced a net transfer of children into the empty spaces.

TEACHING SEQUENCE	COMMENTARY



- What would you expect the distribution of children to be if a similar experiment were continued for many more than twenty spins?

They should realize that eventually all the spaces would have about the same number of children. This number might vary a little by chance, but there would eventually be no more net flow. It is highly unlikely that the whole class

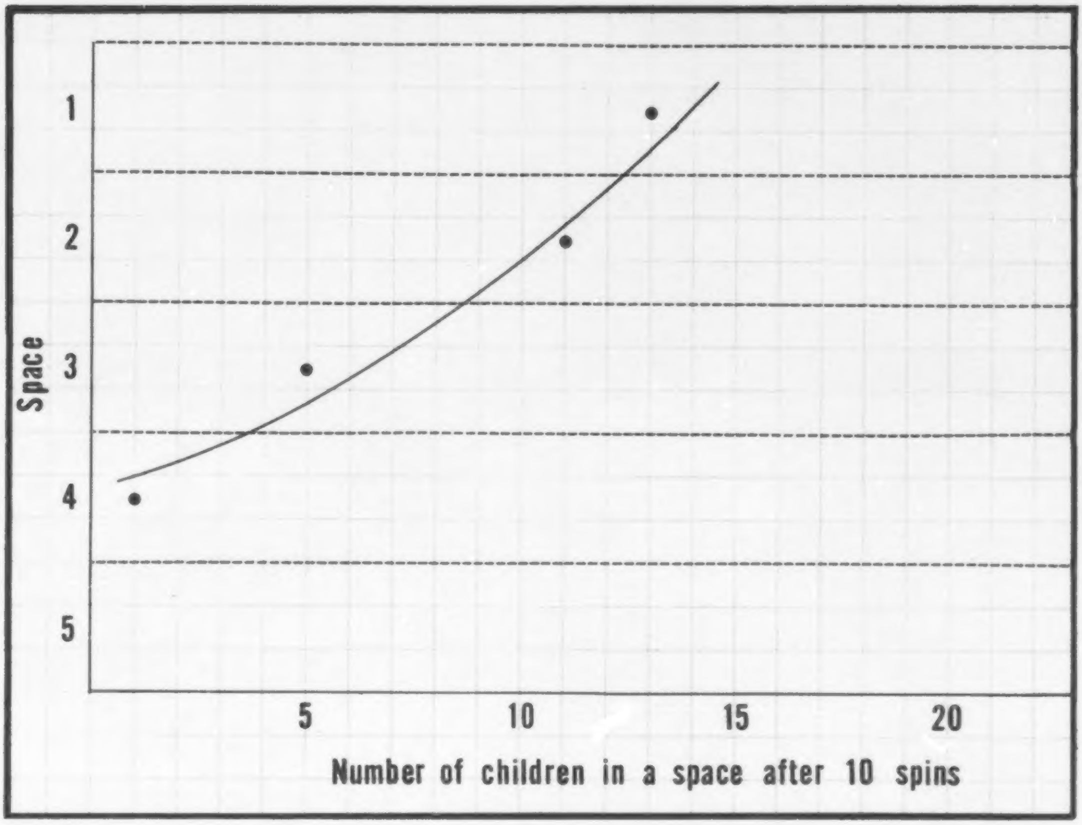
TEACHING SEQUENCE

By this time some discussion may have occured regarding the similarities between this and previous Activities. If not, give out sheets of graph paper and have the children mark in the points for the numbers of children in each space after 10, 15 or 20 spins. A sample graph is shown below.

COMMENTARY

would ever again come together in one space. (On average, it might happen once in every 1,000,000,000,000,000,000,000 spins!)

If children are interested, the experiment could be extended beyond twenty spins. In addition, several repeats of the same experiment could be done and the results averaged for each point. This could give a somewhat clearer graph.



TEACHING SEQUENCE	COMMENTARY
• Looking at the graphs you have drawn, what can you say about the distribution of children in the room after 5 spins? after 10 spins? etc.	The children spread out gradually from the starting spaces.
The children should recognize by now that this game of chance has resulted in a situation producing a "gradient" of concentrations of children. Very likely some will see the similarity to previous Activities--the temperature gradients down the nail as well as the diffusion of the blue food color molecules down the gelatine.	The graph they have just made should remind at least some children of the graph they made in Activity 7 of Minisequence IV. There, the heat energy was at first concentrated near one end of the iron nail. Gradually, the heat energy spread down the nail and the thermometers registered progressively lower temperatures the farther they were from the heat source. Here, the childrens' (net) movement away from space 1 "models" the previous behavior of the heat energy.
	Be sure they realize that what they observed in the tube was the overall effect of the movement of millions of individual blue molecules.
Does this game with spinners provide a reasonable model of the diffusion you observed?	It appears to duplicate the overall effect. Help the children realize that this spinner game provides merely one model for the gradient observed during diffusion. A model is useful if it can explain observed phenomena but it need not be the only one possible.

TEACHING SEQUENCE

Help them consider that since the model resulted in such a gradient of children, and since their movements in creating the gradient were all chance or random ones, perhaps molecules also behave in this manner. The idea that such an orderly pattern can result from a collection of chance movements will be explored further in Activity 3.

COMMENTARY

By "random" be sure they understand moves which could not be predicted ahead for each molecule--although the overall shift was towards the empty (or clear gelatine) region.

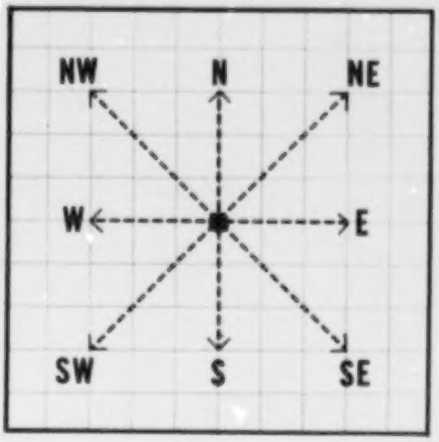
EXTENDED EXPERIENCE:

Some children may be interested in attempting to develop an analog model of the random path of a camphor particle. First they can make a record of the random behavior: Fill a shallow dish--a petri dish is ideal--with cool water and sprinkle a few tiny pieces of camphor on the surface as was done earlier. Then cover the petri dish with a piece of transparent plastic wrap. Have the children carefully focus on a bit of camphor, place a felt-tipped pen on the plastic wrap, and trace the chaotic path of the particle. The wrap will then show a tracing of the path.

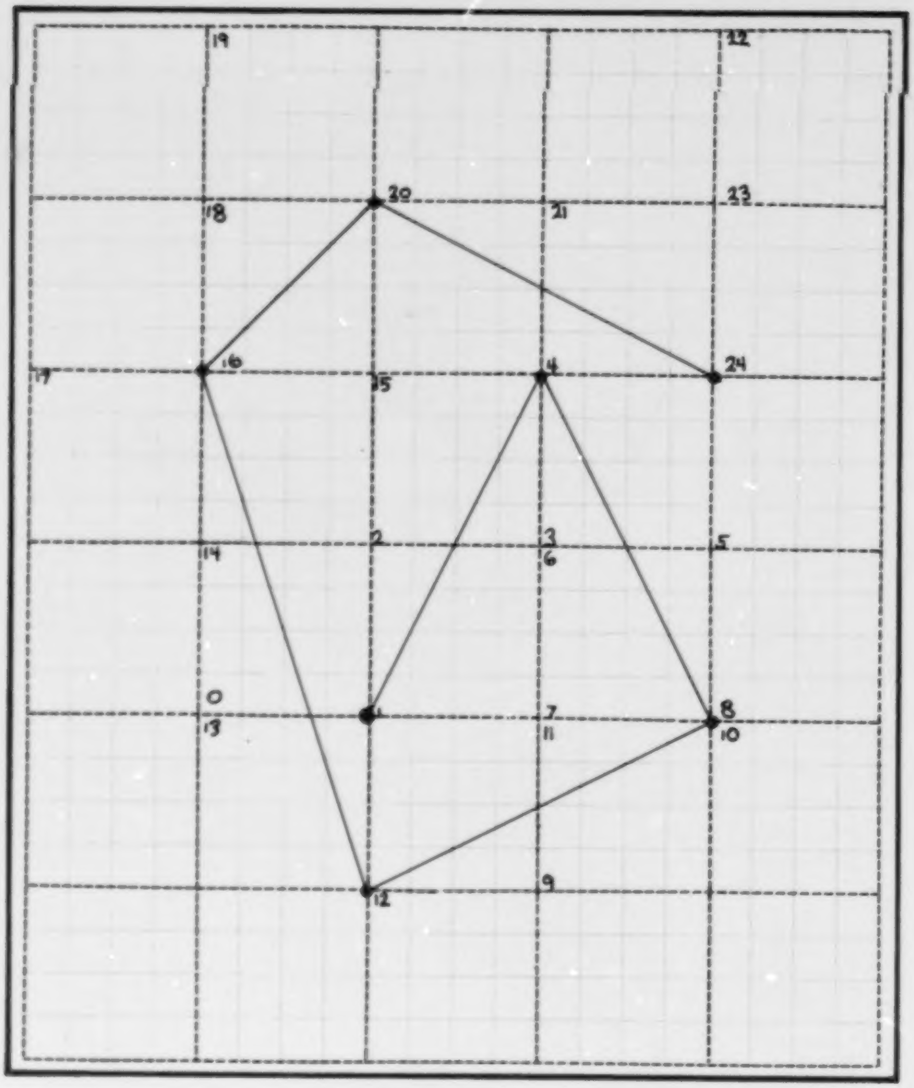
To reconstruct the path of the particle, the children could use a spinner divided into eight equal sectors. The sectors would be lettered N, NE, E, SE, S, SW, W, and NW to indicate the directions in which the particle can move. (Actually, any device which will provide eight different, equally possible outcomes may be used. For example, each child could use an opaque container into which eight, one-inch squares of cardboard, lettered as above, have been placed. Before selecting one of the squares, the container should be shaken vigorously. The squares should not be visible when one is drawn.)

An initial game, or trace of the random walk, might be done as a demonstration on the chalkboard or overhead projector. Then each child could play their own game.

The children should select the center of the graph paper as a starting position for this "camphor particle." Let the object move only to one of eight intersections on the graph, as indicated by the arrow heads in the illustration on page 360. Using graph paper with 4 squares to the inch, the particle can move North, East, South or West four squares or diagonally North East, South East, South West, and North West to the other corners of the larger squares formed by sixteen of the smaller squares. Each possible direction for a move corresponds with a section on the spinner. A replica of the illustration should remain on the chalkboard while this game is being played so that the children may use it to determine the directions of moves.



Consecutive positions of the "particle" should be indicated by numbers on the graph. After four moves have been made, connect the starting position to the fourth position as shown on page 361. Repeat for the next four moves. Continue until about 88 moves have been made on the graph. (One reason connecting every four moves is that it would be very difficult to see all the tiny moves being made. Another reason is that, when tiny particles are actually being buffeted about, we probably do not see every position of the particle but do see an overall effect.



When they are finished, the traces made by all the children should be examined and compared. Although all represent movement on the graph, each move as well as the total trace was quite unpredictable. It is most unlikely that they will discover any two tracings that are alike. Then have the children compare the traces with those made on plastic film of the movement of camphor particles. The similarity will be obvious. In this comparison, might it not be reasonable to associate the unpredictable directions in which the camphor particle moved with the concept of pure chance? Could not the camphor-particle movement be thought of as a random walk?

Activity 3 A Trip by Chance

The object of this Activity is to continue the development of the idea that the pattern of a large number of chance events is orderly and predictable while the result of any one of them is highly unpredictable. The Activity involves a series of moves on a diagram. Each move is dictated by the result of a spin, and making the "trip" can be approached as a game. By combining the results of trips taken by many different travelers in a histogram, the children observe a symmetrical distribution in their destinations.

This Activity, after it has been performed and the results discussed, should help children further to understand the results of the preceding Activity, Random Walks, and should provide a basis for them to understand that the results produced with the so-called Hexstat, available for optional use later, are also due entirely to chance.

MATERIALS AND EQUIPMENT:

Hexstats (optional), available from Harcourt, Brace, Jovanovich, Inc. (see page 459 for ordering address), at least 2 or 3

For each child:

4 different colored pencils

1 spinner from Activity 2

1 copy of Worksheet V-1 (plus scissors and tape)

1 copy of Worksheet V-3

PREPARATION FOR TEACHING:

No special preparation is necessary, other than running off copies of Worksheets V-1 and V-3.

ALLOCATION OF TIME:

This Activity can be completed in about an hour, exclusive of the Extended Experience.

TEACHING SEQUENCE

1. Begin this Activity by distributing fresh copies of Worksheet V-1 and asking the children to cut out the circle and tape it down on their spinners. This time the sectored circle should alternately be marked R (for right) and L (for left). Then give each child a copy of Worksheet V-3 and a colored pencil. Tell them to imagine that they are travelers starting on a trip from the bottom-most circle labeled "start." At the starting circle, two paths go in two directions, and the one to be taken will be decided by spinning the spinner. They will choose the one on their right if it lands on R and the one on their left if it lands on L. They will then advance to one of the two possible outcomes of the first spin, marked 1. From there, the path they choose is determined by the result of a second spin. On the basis of this result, they move to one of the circles marked 2. By thus going to their right or left each time they come to a fork in the path, they continue on their journey until they reach one of the nine destinations marked A through I.

- What are the chances that you will go to your left or to your right at each fork in the path?

COMMENTARY

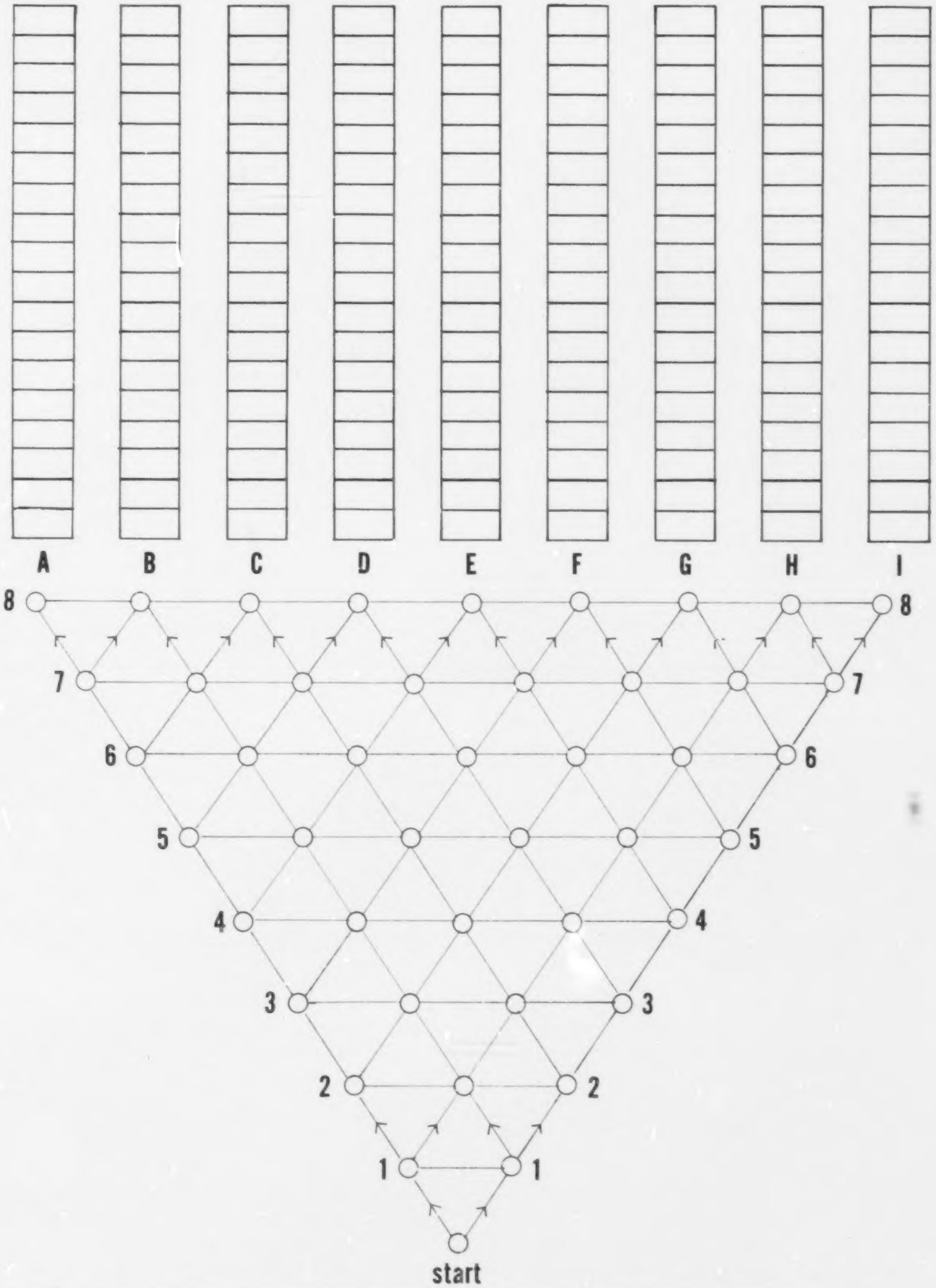
Again they will need scissors and tape.

Why are there 3 and not 4 outcomes of the second spin? Because going left and then right, L-R, gets to the same position as going right and then left, R-L. If the children have studied the commutative axiom in mathematics, they may see that the position reached on the entire trip depends upon the numbers of L's and R's, not their sequence:

[L,R] = [R,L]
[L,R,L] = [R,L,L] = [L,L,R]
[R,R,L,L] = [R,L,L,R] = [L,L,R,R]
etc.

Since the choice is based on the 1 to 1 chance of this particular spinner, the child is just as likely to go in one

WORKSHEET V-3 Name:


A
B
C
D
E
F
G
H
I
8
8
7
7
6
6
5
5
4
4
3
3
2
2
1
1
start

TEACHING SEQUENCE

- What can you predict about which of the destinations you will come to?
- How do your chances of arriving at D compare with your chances of arriving at C? at A? at E? at G?

Before the children begin to travel to their destinations in the manner described above, ask each child to predict which of the nine destinations he or she will come to and then to record the prediction by drawing a box ☐ around the letter and circle predicted. On arrival at one of the nine destinations, the child can make an X over the circle on which he or she landed--or simply color it in with the pencil. Remind them to play fair and not to "fudge" toward their prediction!

When all the children have made one trip, ask how many of them were correct in their predictions.

In a similar manner, each child should follow the paths taken by 3 more travelers.

2. Lead the children to suggest a pooling of all their data, using the rest of the Worksheet. Tell each child to call out in turns the destinations of his or her four travelers. The children can keep tallies, two to

COMMENTARY

direction as the other.

Questions such as these, once raised, can be held for discussion until after the children have traveled several times to their destinations by playing the game.

Probably no more than a very few of the predictions will have been correct. Emphasize that the probability of being correct is very small and that one cannot predict with certainty the exact destination of any one traveler.

Different colored pencils can be used for the path of each traveler.

TEACHING SEQUENCE

a box, in the columns above the letters. When all have finished telling and tallying, each child should have a histogram of the pooled data. An example of one such histogram is shown on page 367.

- What do you observe about this histogram?

- How do you account for the orderly distribution of the results?

During the discussion of the questions raised at the beginning of the Activity, it should be brought out that: (1) Any destination for a given traveler is possible. The destination cannot be predicted with certainty. (2) The results of a large number of chance events produce a pattern that is fairly symmetrical, with the greatest number of travelers arriving at the center of the pattern and with a decreasing number arriving at the successive destinations to the right and the left of center. (3) For a large number of travelers, the pattern of their

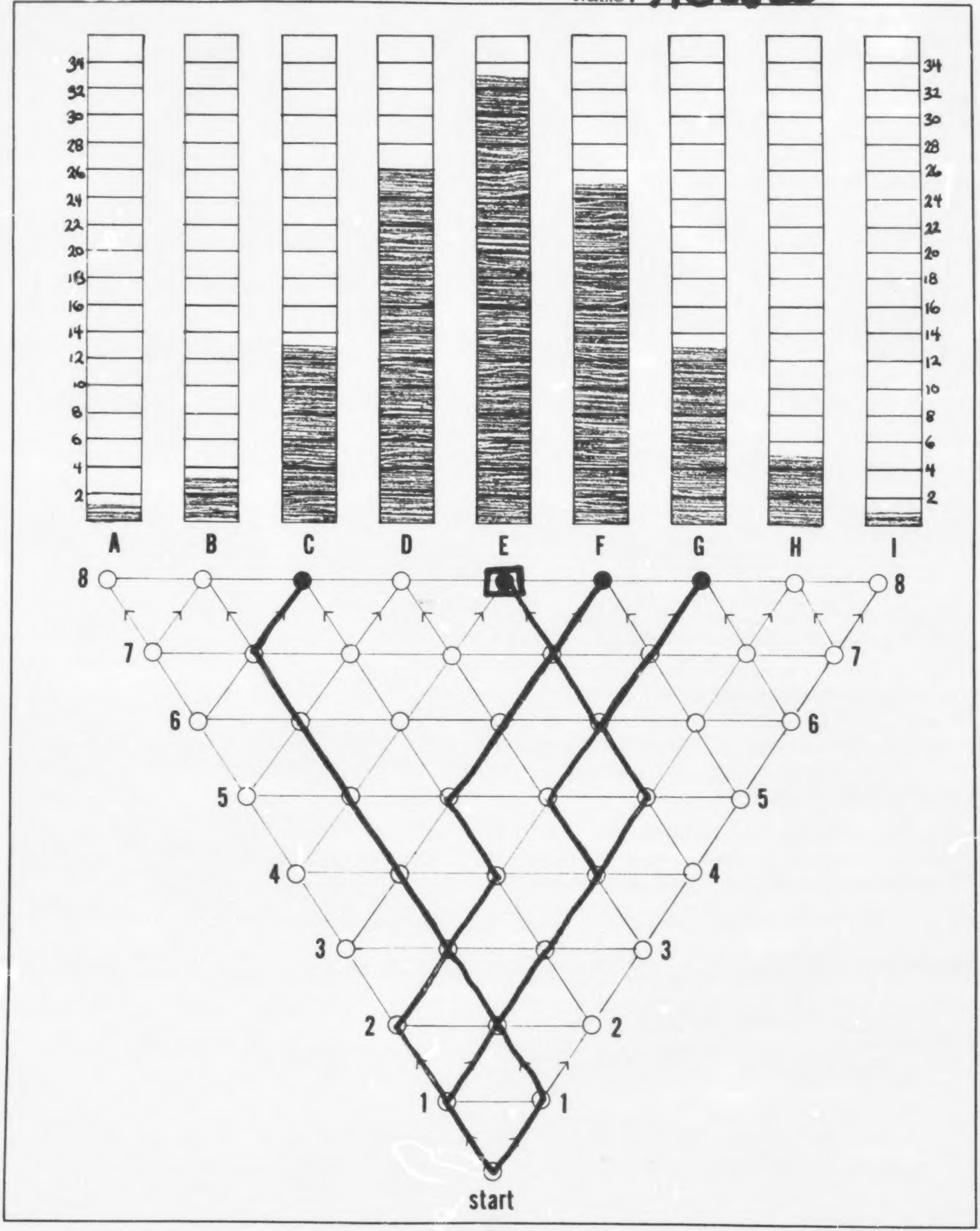
COMMENTARY

It can be expected to be fairly symmetrical, and the chances that a traveler will reach any of the destinations can be estimated with reasonable accuracy. For a class of 30, the theoretical expectations that the travelers will end up at the various destinations are shown below.

Destination	Number of Travelers
A	1
B	4
C	13
D	26
E	32
F	26
G	13
H	4
I	1

Even though it was possible for any given traveler to end up at any one of the destinations (although not equally likely), and even though the individual paths followed were determined solely by successive chance events, collectively the results were patterned as they were partly as a result of the rules and restraints of the game and partly because a large number of travelers was involved.

For example, regardless of how many travelers there may be, WORKSHEET V-3 Name: Howie



TEACHING SEQUENCE	COMMENTARY
destinations is predictable, because of the "overlaps" built into the diagram.	there are only nine "rooms at the inn." Since everyone has to be someplace, some "roommates" are necessary. Furthermore, there are some rooms more accessible than others--that is, there are more ways to get to them. Thus the accessible "rooms"--such as D, E, and F--have more occupants, while the less accessible "rooms"--such as A, B, H, and I--have fewer occupants.

EXTENDED EXPERIENCE:

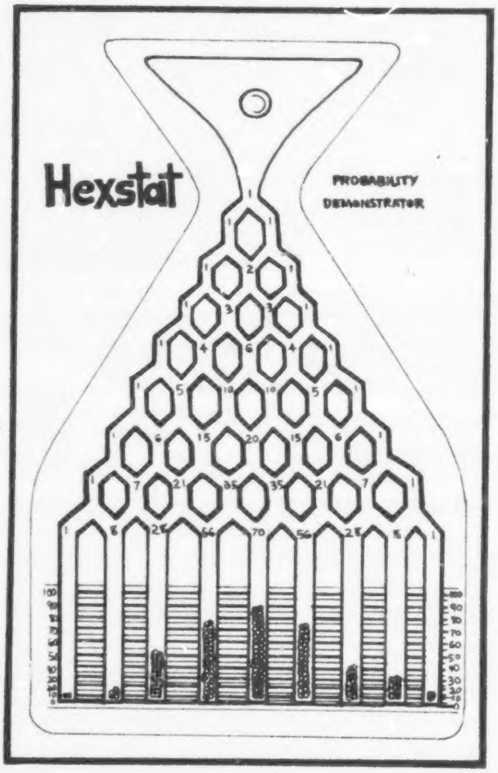
A Hexstat is a device for demonstrating probabilities. It closely resembles the game the children have been playing and receives its name from the hexagonal shape of the pathway segments. (Comparable pathway segments in the preceding game were rhombohedral.) At the top of the Hexstat are many tiny balls which can fall together through a funnel into the various pathways. There is one ball of a different color so it is possible to consider the destination of a single ball apart from the others. When they fall, the balls form a symmetrical distribution at the bottom of the device, like the one the children observed on their histograms.

Children are generally very enthusiastic about this activity and it is well worth the small expense involved in obtaining at least a few of them. Here is the report of one teacher who used the Hexstat:

> The children had no difficulty understanding that at each fork any ball could move either to the right or left and that there was an equal chance that it would move in one of these two directions. We compared this with the toss of a penny, where the possibilities are the same.
>
> I asked them what would have to occur in order for a ball to land eventually in either the far left or far right vertical column at the bottom of the Hexstat. Most children were able to see that it would have to move in the same direction at each of the eight forks in its path. When asked how this would compare with a coin toss, all could see that it would be comparable to tossing 8 consecutive heads or tails, which would be highly improbable.

The children were quite interested in the fact that although the balls seemed to be going every which way, the overall result was always an orderly distribution at the bottom of the board.

Their attention was drawn to the brass colored ball in the collection. They were asked to tip the board so that all the beads went into the reservoir and to locate the brass ball. I then asked them if they would like to predict the path it would take. There was an almost unanimous "Oh, no" response. They observed several falls of the balls and noted the channel in which the brass ball landed. All the children seemed to understand that the greatest probability of its landing would be toward the center and the least toward the ends.



Be alert to the possibility that some children may obtain lopsided (skewed) patterns when the Hexstat card is tilted. You may wish to run a quick travelers game with 4 R's and only 2 L's on the spinners, to show a similar "tilt" effect.

Activity 4 The Record of a Geiger Counter

The purpose of the concluding Activities in this sequence is to help the children realize that order can be brought out of random events not only in "games" but also in nature itself. One example of randomness in nature are the events recorded by a Geiger counter. The children count the clicks produced by the counter at 5- , 10- , 20- , 60- , and 120-second intervals. When counted in very short intervals, the data seem to be chaotic and unpredictable; predictable behavior is obtained when the size of the sample--that is, the time interval--is increased: When they make histograms of their data, they find that the data gradually converge on an average number of counts per minute which cannot be predicted for the smaller time intervals but can for the larger ones.

MATERIALS AND EQUIPMENT:

1 Geiger counter or a prepared tape recording of a Geiger counter and recorder (see Preparation for Teaching)

1 clock with sweep second hand, or a stop watch

For each child:

1 Worksheet V-4

1 piece of graph paper, 4 sq/in. (or 2/cm)

PREPARATION FOR TEACHING:

For this activity, you will either need to borrow a Geiger counter or make a tape recording of one. If you can arrange to borrow a counter, ask the lender how to adjust the voltage of the instrument so that between 10 and 20 clicks per minute are heard. If the clicks occur more rapidly than 20/min., the children will not be able to count some of them that come rather close together. If the rate of clicks is slower, the children will lose interest during some of the longer periods of time when no clicks are produced. If it is not possible to borrow a Geiger counter, arrange to have a tape recording of the clicks made. (Some teachers prefer to use a tape recording of the counter even if they could bring it into the classroom because the children are so curious about the knobs, meters and lights on the counter that they become distracted from the central purpose of the Activity.) A simple cassette recorder can be used to record the clicks for 15 minutes and then play them back.

If it is not possible even to obtain a Geiger counter to make a tape recording, you can make a tape recording without one using the chart on pages 489 and 491 at the back of this Guide. Simply tear out the pages, as with the Worksheets, and tape or paste them together to form a single sheet. The chart is a visual representation of data obtained from an actual Geiger counter--the dots represent the random clicks. With the chart, use the following procedure:

1. Choose a location near a large clock with a sweep second hand, or use a stop watch.
2. Set up the recorder so it is ready to record. The microphone should be placed several inches from where the noise or click will be made.
3. Hold a noise maker in one hand. (A sharp, clear, distinct click is desired. This is obtained by hitting together two objects. Examples: a spoon struck against the desk top, one large metal washer struck against a second washer on the desk, etc. The striking motion must be easy and done without looking with only one hand.) The index finger of the other hand should serve as a place indicator on the time line of the chart.
4. It is necessary to watch the clock and follow the time line on the chart at the same time. Practice running your finger across the time line while watching the clock. Your finger should cover a second on the time line while the clock moves a second. When you come to a a mark on the time line, produce a click with the noise maker. For example, a click would be made at 1 sec, 5 sec, 7 sec, 10 sec, 12 sec, 15 sec, etc.
5. You are now ready to make a practice tape. Turn on the recorder and actually record for a minute or so according to the above instructions.
6. Play back what you have recorded to make certain everything is O.K.
7. If you are satisfied with what you have recorded, you are ready to proceed with the actual recording. Start at the very beginning of the time line. When you reach the end of a minute, go right ahead with the second minute, etc.
8. Continue the process for 15 minutes. If you wish, you can have rest periods during the 15-minute interval by

turning off the recorder at the end of any given minute.

ALLOCATION OF TIME:

The children will need 1-1/2 to 2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Either bring out the Geiger counter and adjust the voltage so that there are between 10 and 20 clicks per minute or turn on the tape so that the children can hear the clicks. They should listen to them for a minute or so.	If you are using an actual counter, let the children observe and get used to the instrument before you start using it in the Activity. If you are using a tape, explain how it was made. Note, however, that the purpose of the Activity is not to get into a discussion of radioactivity or Geiger counters. A Geiger counter--which is named after Hans Geiger, a German physicist--consists of a gas filled tube and associated electronic equipment used to detect and record nuclear radiations such as cosmic rays or other subatomic particles. It is a perfectly harmless instrument which records the so-called "background" radiation even when there is no radioactive source near the counter. The sounds produced are caused by radiation that comes down through the atmosphere, called cosmic radiation, as well as the radiation from small amounts of naturally occuring radioactive materials in the ground, in building materials, etc. Whenever one of these particles with sufficient energy passes through the counter, a noise or click is produced in the loudspeaker. Since their time of arrival is completely unpredictable, the

TEACHING SEQUENCE

- Do you observe any pattern as to when the clicks occur? How many clicks do you think there are per minute?

Previously the children have found that a pattern does exist if one considers a large number of random events. Suggest that they count the clicks over longer intervals of time to see if they can make a prediction on that basis.

They could start by counting the clicks over several 5-second intervals. Distribute Worksheet V-4 and show the children how far the second hand on the clock has to move for 5 seconds. Tell them they must decide where on the clock they are going to start counting. When the second hand gets to this place, say the 12 or the 6, they should start to count. The number of clicks they hear in the 5 seconds will be recorded in the third column on the Worksheet. They may hear no clicks or perhaps as many as 3 or 4 in this time interval.

The children are now ready to take their data. They will

COMMENTARY

clicks on the tape are random. Two clicks could come very close together, or there might be a time interval of 10 or 15 seconds between clicks. There is no observable pattern.

It will help the children if you turn on the tape recorder and go over these steps with them. When everyone seems to have the idea, you might help them get started by doing the first 5-second interval with them.

It might help measuring the various time intervals if you or a child serve as a timekeeper. The timekeeper would watch the clock and give a signal when the time interval begins and ends. For instance, he or she could say "start," watch for 5 seconds, say "stop and record," then pick up on the next multiple of 5.

WORKSHEET V-4 Name:

TRIAL	TIME INTERVAL (sec)	NUMBER OF COUNTS	MULTIPLY BY	CALCULATED COUNTS/MIN.
1	5		12	
2	5			
3	5			
4	5			
5	5			
6	5			
7	5			
8	5			
9	5			
10	5			
11	5			
12	5			
	60 sec=1 min.			
1	10		6	
2	10			
3	10			
4	10			
5	10			
6	10			
	60 sec=1 min.			
1	20		3	
2	20			
3	20			
4	20			
5	20			
6	20			
	120 sec=2 min.			
1	60		1	
2	60			
3	60			
4	60			
5	60			
6	60			
	300 sec=5 min.			
1	120		1/2	
2	120			
3	120			
	360 sec=6 min.			

AVERAGE COUNTS/MINUTE = $\frac{\text{TOTAL COUNTS FOR ALL TRIALS}}{\text{TIME IN MIN. FOR ALL TRIALS}}$ =

TEACHING SEQUENCE	COMMENTARY
need to make counts of clicks during 12 different 5-second intervals. There should be a break between intervals to record the results.	Some children require time to shift their attention from counting to recording. The elapsed rest interval will not matter so far as the data are concerned.
Repeat the same procedure for 10-second, 20-second, 1-minute, and 2-minute intervals, as indicated on the Worksheet.	If the tape runs out, rewind it, and start it over at the beginning. If you are using a Geiger counter itself, the adjustments must not be changed during the activity. If they are, the data cannot meaningfully be compared because the average counts/min. will have changed.
• On the basis of the counts heard for a particular interval, how many would be heard in a minute? For instance, if 3 clicks were heard in 5 seconds, how many do you calculate would be heard in a minute?	There would be 3 x 12 = 36 counts per minute. The twelve is used as a multiplier because there are twelve 5-second intervals in 60 seconds (a minute).
Sample data and calculations are shown on the filled-in Worksheet on page 376.	The numbers to be used as multipliers for the other time intervals are indicated in the 4th column on the Worksheet. Using these, the children should complete the last column, Calculated counts/minute.
2. The next job is to graph the data. Pass out a sheet of graph paper to each child and ask them to make five histograms, one for each of the different time intervals. The horizontal axis can be labeled Calculated counts/min. and the vertical axis No. of 5-sec intervals, No. of 10-sec intervals, etc. The calculated data for each interval	Using a grid on the chalkboard or overhead projector, help the children to set up, number and label their axes. The numbering of the axes will depend on the data obtained. Be sure they include 0 (Calculated counts/min.) on the horizontal axis.

WORKSHEET V-4

Name: Howard

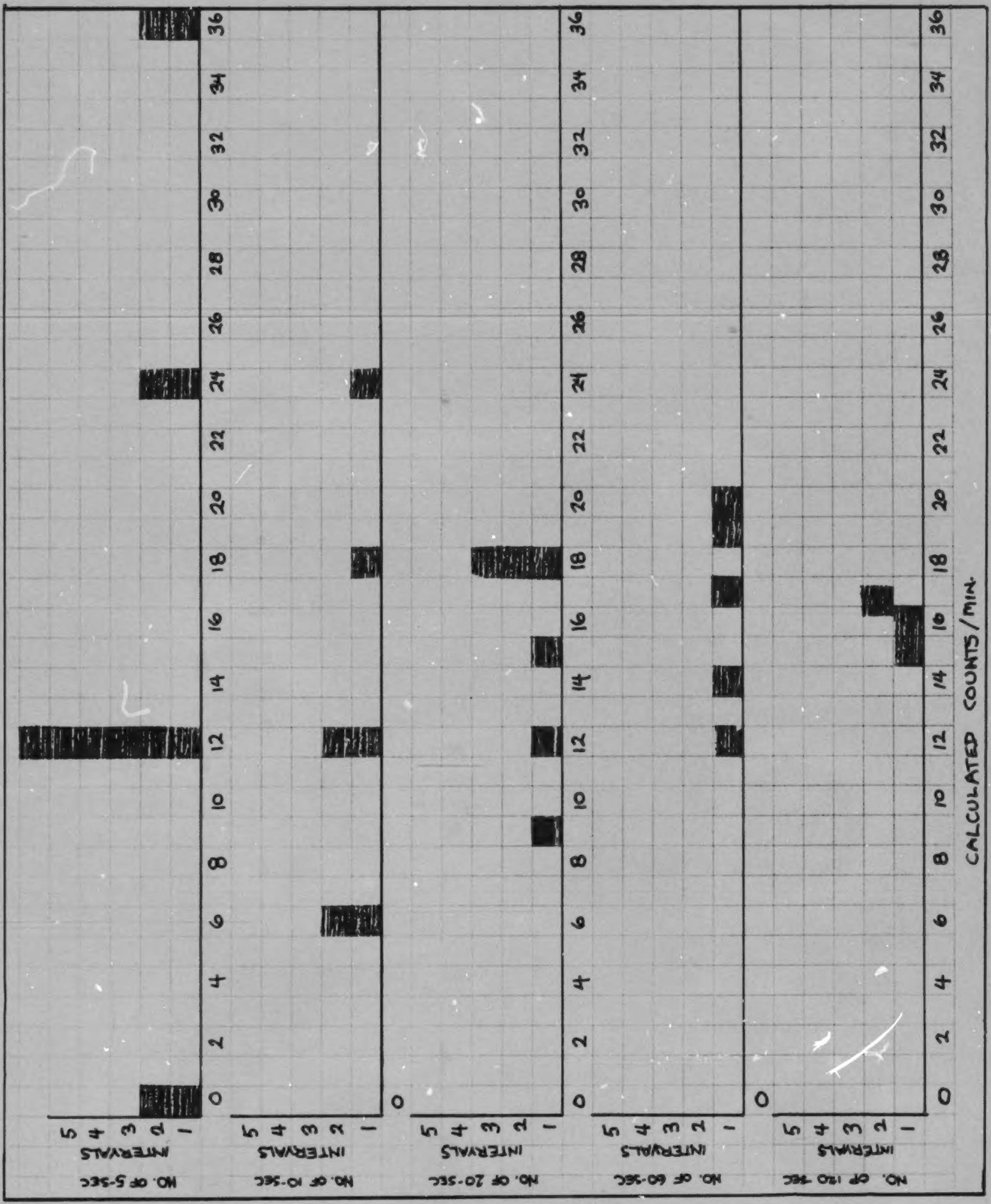
TRIAL	TIME INTERVAL (sec)	NUMBER OF COUNTS	MULTIPLY BY	CALCULATED COUNTS/MIN.
1	5	3	12	36
2	5	1		12
3	5	1		12
4	5	3		36
5	5	1		12
6	5	0		0
7	5	0		0
8	5	1		12
9	5	1		12
10	5	2		24
11	5	2		24
12	5	1		12
	60 sec=1 min.	16		
1	10	2	6	12
2	10	3		18
3	10	2		12
4	10	4		24
5	10	1		6
6	10	1		6
	60 sec=1 min.	13		
1	20	6	3	18
2	20	3		9
3	20	4		12
4	20	6		18
5	20	6		18
6	20	5		15
	120 sec=2 min.	30		
1	60	20	1	20
2	60	17		17
3	60	19		19
4	60	14		14
5	60	12		12
6	60			
	300 sec=5 min.	82		
1	120	33	1/2	16.5
2	120	32		16
3	120	30		15
	360 sec=6 min.	95		

AVERAGE COUNTS/MINUTE = $\frac{\text{TOTAL COUNTS FOR ALL TRIALS}}{\text{TIME IN MIN. FOR ALL TRIALS}} = \frac{236}{15} = 15.9$

TEACHING SEQUENCE	COMMENTARY
can then be filled in. The histograms on page 378 were made using the data on page 376.	
If they have not already done so, ask the children to determine the average number of counts/minute for the entire activity at this point. This is done by adding all the clicks recorded in the data table and dividing it by the total time that the clicks were counted, 15 minutes:	This total time is the total number of seconds during which clicks were counted, not the elapsed time for the activity.

$$\text{AVERAGE COUNTS/MIN.} = \frac{\text{TOTAL COUNTS FOR ALL TRIALS}}{\text{TIME IN MIN. FOR ALL TRIALS}}$$

Have the children draw a vertical line on their graph for the value of the average counts/minute they calculated. This line would be drawn at 15.9 on the histograms on page 378.	This line could be drawn in color.
• Where does the average line fall with respect to the data on each of the histograms?	The average line falls in the midst of all the data. However, it is very noticeable that the data seem to converge on the average as the length of the time interval increases.
• For which time interval was the variability in the data the greatest? The least?	The greatest variation in the data was for the 5-sec time intervals. In the data on page 376, the range in the calculated counts/min. for that interval was 0 to 36. The least variation was in the data for the longest time interval, 120 seconds. There the range was very narrow.
• Suppose a series of trials was made where you counted clicks for 5-minute or even 10-minute intervals and	It could be predicted with confidence that data for 5-minute and 10-minute intervals would pile up tightly


NO. OF 5-SEC INTERVALS
NO. OF 10-SEC INTERVALS
NO. OF 20-SEC INTERVALS
NO. OF 60-SEC INTERVALS
NO. OF 120-SEC INTERVALS
1
2
3
4
5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
CALCULATED COUNTS/MIN

TEACHING SEQUENCE

then calculated the counts/minute from these. What would you predict about the location of the columns if you made a histogram of the data?

- In what sense is there a pattern as to when the clicks of the Geiger counter occur?

This Activity provides a very good example of how natural events can be predicted only on a statistical basis. Conversely, only when one studies individual or small numbers of events, does the random character of natural phenomena become evident. In the next Activity the children will investigate another type of natural phenomenon: eye color in house flies.

COMMENTARY

around the average line since the variability is all but gone even for 2-minute intervals.

Although it is impossible to predict accurately how many clicks will occur over a short time interval, it *is* possible to make an accurate prediction over longer time intervals. In other words, the random *unpredictable* occurence of individual clicks *becomes predictable* when large numbers of them are taken into account. In effect, the longer time periods represent progressively larger *samples*, and the children have learned in earlier grades of COPES that a larger sample provides a better basis for prediction than a smaller sample.

Activity 5 Eye Color in House Flies

In this Activity, the idea of randomness is carried forward into an application of a biological nature, the inheritance of eye color in house flies. In addition to the random process, a property called *dominance* is also apparent in the data presented, and the children are led to discover and label it. In the house fly, the inheritance of eye color displays a simple pattern of dominance in which the cross breeding of purebred red-eyed and purebred white-eyed flies yields all red-eyed flies in the first generation. By analyzing data on such a second generation population, the children observe that the ratio of red-eyed to white-eyed flies is about 3 to 1. (In an Extended Experience, information is provided on how the children can crossbreed house flies and produce such data themselves.) Using red and white discs, they develop a genetic model to explain why there are no white-eyed flies in the offspring of the first cross breeding and how a process of simple random selection could yield such an orderly pattern of 3 to 1 in the second generation.

MATERIALS AND EQUIPMENT:

For each pair of children:

8 transparent red discs or squares, e.g., cut out of red acetate*

6 transparent (clear) discs or squares, e.g., cut out of clear acetate*

2 opaque cups, or small paper bags

1 Worksheet V-5

1 Worksheet V-6

1 Worksheet V-7 (optional)

Housefly *pupae* and associated apparatus for culturing and crossbreeding houseflies (optional)

*Some possible substitutes for the red and clear discs or squares are poker chips, tiddly winks, buttons, etc. It is preferable that they be transparent, but not absolutely necessary. The discs or squares for any given pair of children should have the same size and "feel," however, so that no difference between them can be discerned during the random selection. Sheets of acetate are generally obtainable at hardware or "Five and Dime" stores.

PREPARATION FOR TEACHING:

Unless small red and clear discs or squares are available, you will need to prepare them ahead of time. A few of the children can do this job. Acetate is flexible and can be cut with scissors. (Squares are easier to cut out than circular discs.) Pairs of opaque cups or bags should then be prepared. Six red and six clear discs or squares will be distributed with each pair of cups.

ALLOCATION OF TIME:

The children will need 2 to 3 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Unless you have ordered house flies from a laboratory ahead of time, ask the children to capture some flies before beginning this Activity--perhaps the day before. They should observe the flies carefully, preferably in natural light.	Of course, it may not be the "season" for house flies.
• What color are the flies' eyes?	Wild type house flies have large red eyes which may appear brownish in artificial light. White-eyed flies are very rare in wild populations. However, they have been found and bred in laboratories. If the children can observe flies ordered from a supply house, they will see both eye colors. During their initial observations, some children may be interested in distinguishing male flies from females. The most reliable single way of telling them apart is by examining the spacing between the eyes. The eyes of the female fly are spaced widely apart while the eyes of the male almost touch one another,

TEACHING SEQUENCE	COMMENTARY
	forming a "V" at the top of the head. In addition, the tip of the male's abdomen has a black patch on it; the female's abdomen is more pointed with a single pore at the tip.
• What would you expect would be the eye color of the offspring of a red-eyed female and a red-eyed male? Of a white-eyed female and a white-eyed male?	Most children will probably expect that red will beget red and white will beget white. Discuss in general terms that children also have characteristics that they inherit from both their parents. That is, they tend to be like their parents with respect to eye color, hair color, height, and other features. Some may suggest the gene as a transmitter. However this terminology is not essential to the discussion. The emphasis should be that something carries the message.
	You might want to explain that the children of a given set of parents are referred to as their offspring or as the "first generation." They should also understand that the "second generation" would be the grandchildren.
Tell the children that in the laboratory it is possible to breed red-eyed flies which produce only red-eyed offspring over several generations and white-eyed flies which produce only white-eyed offspring over several generations.	
• Suppose one of these red-eyed flies were to mate with one of these white-eyed flies. What do you predict would be the eye color of the offspring?	Here you may receive all kinds of predictions--including pink eyes and one red eye and one white eye! Accept all suggestions.
Distribute Worksheet V-5. Ask	

WORKSHEET V-5 Name:

Table 1: A FIRST GENERATION POPULATION OF HOUSE FLIES

	Red Eyes	White Eyes	Total
Male	50		50
Female			
Total	100		100

Table 2: A SECOND GENERATION POPULATION OF HOUSE FLIES

	Red Eyes	White Eyes	Total
Male	3,750		5,000
Female			
Total	7,500	2,500	

Table 2a: A RANDOM SAMPLE OF 100 FLIES FROM THE SECOND GENERATION

	Red Eyes	White Eyes	Total
Male	34	14	48
Female	36	16	52
Total	70	30	100

Table 2b: A SECOND RANDOM SAMPLE OF 100 FLIES

	Red Eyes	White Eyes	Total
Male		13	51
Female			
Total	74		100

Table 2c: A RANDOM SAMPLE OF 20 FLIES FROM THE SECOND GENERATION

	Red Eyes	White Eyes	Total
Male	7		10
Female			
Total	13		20

Table 2d: A SECOND RANDOM SAMPLE OF 20 FLIES

	Red Eyes	White Eyes	Total
Male			12
Female			
Total	18		20

TEACHING SEQUENCE	COMMENTARY
them to look at Table 1 which shows the eye color of a first generation of houseflies who had such parents.	Note that the Table shows what is not obtained in such a cross, as well as what is obtained. Such offspring never have one red and one white eye or pink eyes. These are not unreasonable expectations, however. For instance, when a purebred white, short-horn bull is crossed with a purebred reddish brown cow, the calves can either be an intermediate roan color all over or a spotted combination of the two parental colors.
• How many female flies in the first generation had red eyes?	Since there was a total of 100 flies having red eyes, and 50 of these were males, there must also have been 50 red-eyed females.
Ask the children to fill in the space on the Worksheet accordingly.	
• What was the total number of white-eyed flies in the first generation?	Allow time for the children to fill in the remaining spaces on Table 1. The data show that there were no white-eyed flies, either male or female, in the first generation.
2. Now ask the children to look at Table 2 on the Worksheet. This table shows the eye color characteristics of the second generation of house flies.	These flies are the result of random matings among the male and female red-eyed flies of the first generation. They are the "grandchildren" of the two original purebred red-eyed and white-eyed flies.
Help the children complete the blanks in Table 2.	
• How many flies had red eyes in the second generation?	According to the table, there were 7,500 red-eyed flies and 2,500 white-eyed flies in the

TEACHING SEQUENCE	COMMENTARY
• How many flies had white eyes in the second generation?	second generation.
• What is the ratio of red-eyed flies to white-eyed flies?	Be sure that the children see that this is a ratio of 3 to 1. If necessary, set up the numbers as a fraction and simplify it: $\frac{75\cancel{0}\cancel{0}}{25\cancel{0}\cancel{0}} = \frac{3}{1}$ No attempt should be made to convey the idea that the data on the Worksheets in this Activity are "real" in the sense that they resulted from a specific experiment. They are not. But the data are "real" in the sense that they reflect what actually happens when house flies with these characteristics are cross bred--but with certain built-in numerical simplifications, such as the assumption that any given pair of flies produces exactly 100 offspring. In the COPES laboratory, red-eyed flies in the first generation produced 766 offspring, 195 of which were white-eyed and 572 of which were red-eyed. Thus, the ratio of red-eyed flies to white-eyed flies was 2.95 to 1. Such results are typical. While it is quite possible for the children to develop the necessary animal husbandry techniques required to culture flies through their life cycle and also to develop the techniques necessary to cross breed them and produce results like these themselves (see the Extended Experiences at the end of the Activity), the main purpose here is to consider how such orderly population patterns can result from a process of

TEACHING SEQUENCE	COMMENTARY
	random selection.
• What would you expect would be the number of red-eyed flies in a sample of 100 flies from the second generation?	Work a bit on the numerical equivalence by saying that the ratio of red to white is 3 to 1, or 3 red-eyed flies for every 1 that is white-eyed: hence, the precent of red is 75%. Therefore, one would expect 75 red-eyed flies in such a sample.
• Would this number of red-eyed flies be found in *any* 100 flies from the second generation?	No, only in a randomly drawn sample. Review the idea that random sampling means that each fly in the initial population would have an equal chance of being selected for the sample.
• If you took many random samples of 100 flies, would each one of them have 75% red-eyed flies?	No, there would be some variation from one sample to the next. However, the average of many samples should be close to 75% red.
Ask the children to look at Table 2a, complete Table 2b and then compare the data with their prediction.	
• If you took many random samples of only *20* flies, how would they compare to the larger samples?	The percentage of red-eyed flies would be even more variable; i.e., some samples would have much smaller and some much larger percentages. The average of several samples, however, should again be close to 75%.
• Ask them to complete Tables 2c and 2d and compare with the expected.	See if the children realize the similarity between these data and their findings in the previous Activity, where the greatest variation was for the shortest, 5-second time interval. The least variation was in the data for the longest time interval, 120 seconds.

TEACHING SEQUENCE	COMMENTARY
3. After the children have completed their entries in Tables 2 through 2d and compared the results from the point of view of sampling, raise the following question if the children have not already done so: • Why should red-eyed flies have white-eyed offspring?	Some children may suggest that the white-eyes are "accidents." You should discuss this possibility: If these white-eyed flies are "accidents," why shouldn't some of the first generation flies have had white eyes by accident?
Elicit the idea that somehow the white-eyed characteristic must be present in the red-eyed flies, even though it doesn't show up--otherwise it could not be transmitted to their offspring. Then suggest that the children try to set up a model which would show how these eye color characteristics could be transmitted from one generation to the next. Such a model should account for the "disappearance" of the white-eyed characteristic in the first generation and for the specific ratio of red- to white-eyed flies which is observed in the second generation. Show the children six red discs (or squares), six clear discs (or squares), and a pair of opaque cups. Suggest that one of the cups represent the male parent and the other the female parent.	
• If the red discs represent red-eyed factors which can be passed on to offspring and the clear discs	Since the original parents were purebred red eye (whether male or female) and purebred white eye (whether male or female),

TEACHING SEQUENCE	COMMENTARY
represent white-eyed factors, how could the discs be put in the cups to represent the original white- and red-eyed parents?	they must have possessed only red-eye factors and only white-eye factors respectively. This situation could be represented by putting all the red discs in one cup and all the clear discs in the other.
Put the six red discs in one cup and the six clear discs in the other.	
• Assuming that each parent contributed characteristics to the offspring at random, what combinations of characteristics are possible in the first generation?	It is also assumed that each parent makes an equal contribution. This is indeed the case.
Ask a child to come up and, without looking into the cup, make a blind selection of a disc from the cup representing the purebred red-eyed parent. Ask another child to come up and do the same for the cup representing the white-eyed parent. The results of their selection--one red and one clear disc, representing the characteristics inherited from these parents by one offspring--should be recorded on the chalkboard. The discs should then be returned to their respective cups and the contents of the cups shaken.	The selected pair of discs should be put one on top of the other and held up for the other children to see.
Next, ask another pair of children to come up and do likewise--blind select a disc from each cup, record the results, and return the discs to their respective cups.	Eventually the children will realize that they are not going to come up with any other combination of discs than a red and a white: (RW or WR). See Activity 1, "Selecting Marbles," of Minisequence V in Grade 5 for some earlier experience with making inferences about a population on the basis of blind selections.

TEACHING SEQUENCE	COMMENTARY
• If the first generation of house flies all inherit a red and a white factor from their parents, why are they all red eyed?	The red-eyed characteristic is "dominant" in house flies while the white-eyed characteristic is described as "recessive." The children may suggest that red is "stronger" than white in some way.
Some of the children may already have noticed that pairing a red and a clear disc results in a red color. That is, if the pair is held up to the light, it looks red, illustrating the idea of dominance. If they have not noticed this feature of the model, point it out to them during this discussion.	
4. It is clear from Table 1 that equal numbers of the first generation flies are males and females. Using the discs and the cups, how could we represent what factors these flies could pass on to their offspring?	Since each of the offspring in the first generation inherited one red and one white factor, this time each cup would contain an equal number of red and white discs.
• If we continue to have six discs in each cup, how many would be red and how many white?	Each cup would contain 3 white and 3 red discs.
• How could we determine what combination(s) of characteristics are possible in the second generation?	The children will probably suggest drawing a disc from each cup to make pairs and recording the results just as they did before.
Ask the children to work in pairs. Distribute two opaque cups, 6 red and 6 white discs, and a copy of Worksheet V-6 to each pair.	
They should put 3 red and 3 white discs in each cup. Then, with one child in each	

WORKSHEET V-6 Name:

SELECTION	FACTOR INHERITED FROM	
	Female Parent	Male Parent
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

SELECTION	FACTOR INHERITED FROM	
	Female Parent	Male Parent
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

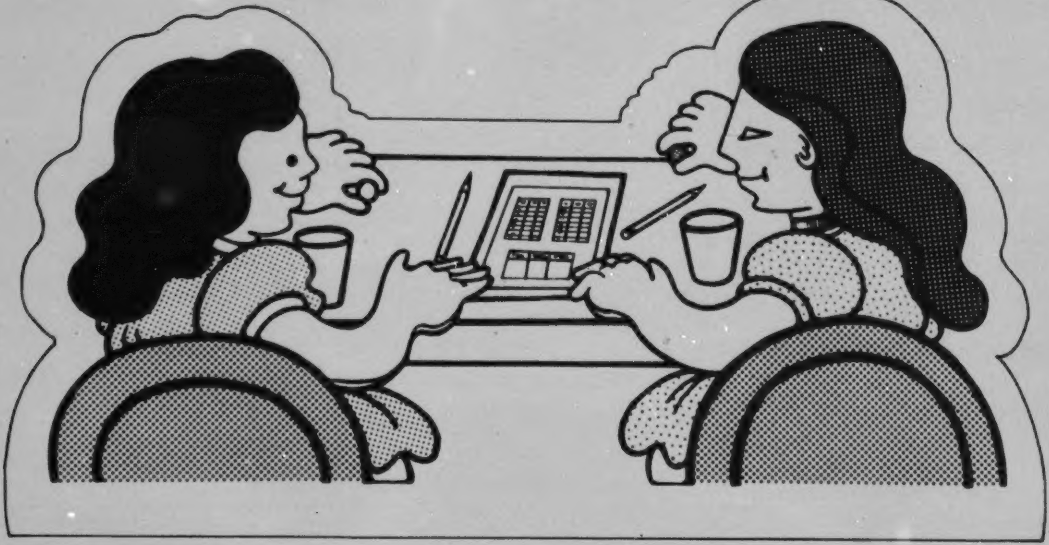
KINDS OF COMBINATIONS OF FACTORS	NUMBER OF EACH KIND OF COMBINATION	EYE COLOR OF THE COMBINATION

TEACHING SEQUENCE

pair being the selector for the male parent and the other child for the female parent, they should proceed to blind draw 20 times and record the results on the Worksheet. They can use a capital R for the red disc and a capital W for the white (clear) one.

COMMENTARY

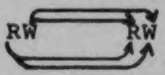
After each draw, the discs should be returned to their respective cups so that each cup contains 3 red and 3 white discs throughout. After each return, the cup should be shaken to ensure mixing of the discs.



A set of typical data are given below:

1. RR
2. RW
3. WR
4. RR
5. WR
6. RW
7. WW
8. RW
9. WW
10. RR
11. RW
12. WW
13. WR
14. WR
15. RW
16. RW
17. WW
18. WW
19. RR
20. RW

If there are fewer than 15 pairs of children gathering data, you may want to have each pair draw more than 20 times so that when the data for the whole group are combined, at least 300 selections will be represented. A total of 400 selections is even better. Then there will be close to 100 WW (white-eyed) combinations and close to 300 RR, RW, and WR (red-eyed) combinations.

TEACHING SEQUENCE	COMMENTARY
• What are the possible combinations of factors in the second generation of house flies, according to this model?	As a result of this activity, the children should see that four different kinds of combinations are possible in the second generation: RR, RW, WR, and WW. You might want to show them the following shorthand method for finding the possible combinations:  1st generation RW RW 2nd generation RR RW WR WW
• How many of each kind of combination did you have?	In the sample data cited above, there were the following number of each combination: RR 4 RW 7 WR 4 WW 5
Even now some children may see the pattern that is emerging from this process of random selection. In any case, pool the data of all the pairs of children and then ask the following questions:	The frequencies for each combination are, theoretically, equal; however, in samples this small, there may be a few extreme values. The pooled data should show each frequency close to 1/4 the total.
• What would be the eye color of the flies with the RR combination of characteristics?	These flies would obviously be red-eyed since no other kinds of factors than red-eye determiners are present. These flies are purebred reds--just like one of their "grandparents."
• Would any other flies be red-eyed?	Here the children should see that, just as in the first generation, a combination of R and W will yield a red-eyed fly because red is dominant over white.
• What would be the eye color of the flies with the WW combination of characteristics?	These flies would have to be white-eyed for the same reason that those bearing RR would be red-eyed.

TEACHING SEQUENCE	COMMENTARY
Now return again to consider Table 2. Are the frequencies similar to those obtained from the model?	Help the children to see that one-fourth RR, plus one-half mixed R and W, could lead to three-fourths, leaving the one-fourth WW which fits the frequency of white eyes in Table 2. The proportions are about the same.
Apparently random processes can account for certain orderly patterns observed in nature.	

EXTENDED EXPERIENCES:

1. It can be a very enriching experience for children to culture and cross-breed red- and white-eyed houseflies themselves. Eggs, *larvae*, *pupae*, and adults are relatively easy to manipulate and the life cycle requires only sixteen or seventeen days under classroom conditions. (Children who made a fruit-fly "farm" in Activity 5 of Minisequence I will already be familiar with the life cycle of flies.) Of course, the Activity would have to be extended over a longer period of time but it is well worth it to see the excitement of children when they obtain all red-eyed flies in the first generation and the specific ratio of white-eyed flies reappearing in the second generation. In this way of handling the Activity, the children could obtain the data themselves and therefore not use the Worksheet description of results.

If you want to do this, it would be helpful to send for the following booklet, obtainable from Educational Science Consultants in San Leandro, California: "The Housefly as a Classroom Animal." They can also supply a special housefly kit which includes the booklet and apparatus for setting up two fly colonies. Housefly *pupae* must be ordered separately. These are available from Continental Biological Labs in Chicago. The full addresses of these suppliers are provided in the Materials and Equipment section at the back of this Guide.

2. Children of high ability may be challenged by the opportunity to consider the eye color characteristics of the third generation of houseflies. Worksheet V-7 includes information on the offspring of a selected sample of 100 white-eyed flies and of a selected sample of 100 red-eyed flies from the second generation. (You may need to discuss selection versus random sampling. In the former, a characteristic is chosen and only members of the population having that characteristic are selected. With regard to other characteristics, however, the subsequent choice is by

WORKSHEET V-7 Name:

Table 3: A SELECTED SAMPLE OF 100 WHITE-EYED FLIES FROM THE SECOND GENERATION

	White Eyes
Male	
Female	50
Total	100

Table 4: OFFSPRING OF SELECTED WHITE-EYED SAMPLE

	Red Eyes	White Eyes	Total
Male			5,000
Female		5,000	
Total		10,000	10,000

Table 5: A SELECTED SAMPLE OF 100 RED-EYED FLIES FROM THE SECOND GENERATION

	Red Eyes
Male	50
Female	
Total	100

Table 6: OFFSPRING OF SELECTED RED-EYED SAMPLE

	Red Eyes	White Eyes	Total
Male		556	5,000
Female			
Total	8,889	1,111	10,000

random sampling.)

After distributing Worksheet V-7, the following sequence of questions might be raised with the children:

• What would you expect would be the eye color of the offspring of the flies from the white-eyed sample?	The children will probably be able to predict that the offspring of the white-eyed flies should all be white-eyed.
• What would you expect would be the eye color of the offspring of the flies from the similarly selected red-eyed sample? What would all these flies have in common?	Here the children may be more uncertain. They should realize, however, that all these flies have at least one R factor. Otherwise they would not be red-eyed. Genetically they can be described as RR, RW and WR. The question is, would there by any white-eyed offspring of such flies.
• What eye color is found in the offspring of such a sample of white-eyed flies?	After filling in Table 4, the children should notice that all the offspring of the white-eyed flies are white-eyed, as expected.
• What eye color is found in the offspring of the red-eyed sample?	After filling in Table 6, the children will observe that while most of the offspring are red-eyed, as might be expected, one-ninth of the offspring have white eyes.
Direct the children's attention to Table 6 and ask them how the data are both like and unlike those in Table 2.	In this third generation, an even smaller proportion of the offspring of red-eyed flies are white-eyed than was the case in the second generation--1/9 as compared with 1/4. In both cases, though, a specific ratio exists.
• How could we find out if these data can be accounted for using the model of random selection we have developed? What colors and numbers of discs should be put in each cup?	Since the RR, RW, and WR factors are the only ones present in both males and females, representing such a situation in the cups would require twice as many red discs as white discs in each one. Maintaining a total of six, there would be 4 R and 2 W in each cup.

Distribute fresh copies of Worksheet V-6 and encourage the children to see if by again selecting discs randomly, 1/9 of the outcomes are WW. They should indeed obtain such results. One group counted 44 WW's out of 400 selections.

Some children may be able to see why 1/9 of the flies from such a selected sample would have to be white-eyed by working out the following table of possible combinations:

	RR	RW	WR
RR	RR RR RR RR	RR RR WR WR	WR WR RR RR
RW	RR RR WR WR	RR RW WR WW	RW RR WW WR
WR	WR WR RR RR	WR WW RR RW	WW WR RW RR

From the table it can be seen that 4/36 or 1/9 of the outcomes are WW. Here again, an orderly pattern has emerged from a process of random matings.

Minisequence VI
Towards an Ideal Mechanical System

In this final Minisequence of the COPES program we return to the idea of conservation of energy and focus on conservation in mechanical systems. From the activities and discussion in Grade 5, Minisequence II and IV, we found that it is difficult to demonstrate energy conservation in such systems because of friction. The effect of friction in all cases is to convert some of the mechanical energy to heat energy as a result of the rubbing of 2 surfaces against each other. Thus is appears that energy is not conserved in a bouncing ball, for example, because the ball eventually comes to rest. However, it is only that the energy is not conserved as mechanical energy; the total energy (mechanical plus thermal) is conserved.

If it were possible to eliminate friction completely, mechanical energy could be conserved. In fact, in the design of a practical mechanical system one always seeks to minimize friction so as to decrease the generation of heat energy and thus increase the overall efficiency of the system. Lubricants such as oil are frequently used on parts rubbing over one another in order to decrease the friction between them. In the case of the bouncing ball, the friction or rubbing is internal: As the ball hits the floor (or any surface), it compresses; after it rebounds it returns to its original shape. Layers of rubber "slide" over one another, converting some energy to heat during the compression and return to shape. If the internal sliding or friction could be lessened, we would have a "better" ball, which would bounce higher and continue bouncing longer.

We know that it is impossible to eliminate friction completely in a real system. How then can we establish the principle of conservation of energy? Only by inference from experiments in which the frictional effects are progressively diminished. That is, by studying systems having less and less friction, and finally extrapolating these observations to the ideal case of zero friction. In this way one concludes that without friction, mechanical energy would be conserved.

Mechanical energy was introduced in Grade 5, Minisequence II. There the children saw that there are two forms of mechanical energy, both measured by the amount of work that the system is capable of performing. One is *potential energy*, or energy due to the position of an object, and the other is *kinetic energy*, which is energy due to the motion of an object. In many mechanical systems there is a continual interchange between these two forms of energy. For instance, in the bouncing ball, the potential energy of the ball at its highest point is converted to kinetic energy as the ball drops. When it rebounds upward, the kinetic energy is converted back to potential energy. The ball fails to return to its original height, however, because as it rebounds some of its energy is "lost" in the form of heat. As stated before, this is caused mainly by frictional effects within the ball.

Another mechanical system that more nearly approaches the ideal is the simple pendulum. Here the frictional effects (occurring at the point of suspension where the string rubs against a supporting surface and as a result of resistance of the air as the bob moves through it) can be made so small as to appear negligible. The potential energy of the bob at its highest point is converted to kinetic energy as it moves down and through the midpoint. The kinetic energy is then converted back to potential energy when it swings up and over to the other side. The loss of mechanical energy in each swing cycle can be very small, but we know that even in such a system the energy is eventually degraded to heat and the pendulum comes to rest. What this means, in effect, is that perpetual motion cannot be achieved in a practical system, which should not be surprising. Nevertheless, such nearly ideal systems do help one come to the conclusion that in the absence of friction, mechanical energy would be completely conserved; e.g., a pendulum would continue swinging forever.

In this way the Activities in this Minisequence lead from a consideration of inefficient mechanical systems, in which there are obvious energy losses due to friction, to the culminating Activity involving a system in which the losses are much less: the pendulum, which may be regarded as a nearly ideal mechanical system. Thus the primary objective of the Minisequence is to guide children through a series of experiences from which they are able to make the final leap to the ideal case.

The following concepts are developed in Minisequence VI:

1. The total amount of energy (mechanical plus thermal) in a system remains constant.

2. In an ideal system, the different forms of mechanical energy (potential and kinetic) can be converted from one to the other without any loss of mechanical energy.

3. On impact, the kinetic energy of an object can be transformed into thermal energy.

4. The amount of work done to increase the gravitational potential energy of an object (lifting it against gravity) does not depend on the path through which the object is raised.

5. A loss in the mechanical energy of a system may be accounted for by the production of thermal energy due to frictional effects.

Activity 1 The Bouncing Ball

This first Activity consists of three parts. All of them deal with the same basic phenomenon--the conversion of some mechanical energy into heat energy when a rubber object (or any other kind) is stretched or compressed, as in a bouncing ball. Such observations are designed to lead the children to realize that the apparent failure to conserve mechanical energy in a given system may be attributed to the conversion of some of it to heat.

All children have had experience with a bouncing ball. They know that left to itself such a ball eventually comes to rest on the floor. In the first part of this Activity a bouncing ball is regarded from the standpoint of its energy. It is a mechanical system whose energy is continually interchanged between potential and kinetic: At the highest point in its bounce, the *potential* energy of the ball is at a maximum. As it drops, the ball is moving and just before it hits the ground it is moving most rapidly. At this point, its *kinetic* energy is at a maximum. As the ball continues to bounce up and down, its mechanical energy is gradually dissipated (because of internal friction). What becomes of the energy is not obvious, although some children may infer that it was transformed to heat energy. In the next part of the Activity, they observe the heat energy generated as another piece of rubber (a pencil eraser) is repeatedly flexed by pounding it on a table top. The conclusion to which the children are led at that point is that some of the mechanical energy of the bouncing ball was also changed to heat energy. They are then prepared to study other bouncing balls, some of which bounce "better" than others because they lose less energy in the form of heat at each bounce.

MATERIALS AND EQUIPMENT:

1 ball, hollow, rubber, approx. 2 in. (5 cm) in diameter

1 ball, "Superball," approx. 1 in. (2.5 cm) in diameter, if available

1 ball, sponge rubber, approx. 2 in. (5 cm) in diameter

1 ball, ping pong

1 set of felt marking pens of different colors, including black

1 sheet wrapping paper, approx. 2 ft by 6 ft (60 cm by 180 cm)

1 piece of rug or carpeting, approx. 2 ft by 2 ft (60 cm by 60 cm)

masking tape

For each child:

2 pencils (unsharpened) with erasers

1 rubber band, 2 in. or 2-1/2 in. long (5 cm or 6 cm)

1 sheet graph paper, 4 sq/in. (2 sq/cm)

PREPARATION FOR TEACHING:

Using the black felt marking pen, draw horizontal lines across the wrapping paper (lengthwise) every six inches (15 cm) and number them. Select a part of the room where the (hard) floor is fairly smooth near the wall, and fasten the paper to the wall with masking tape so that one edge of the paper touches the floor. The balls will be bounced in front of this lined paper, which will allow the children to determine the height of each bounce. (See the illustration on page 402.)

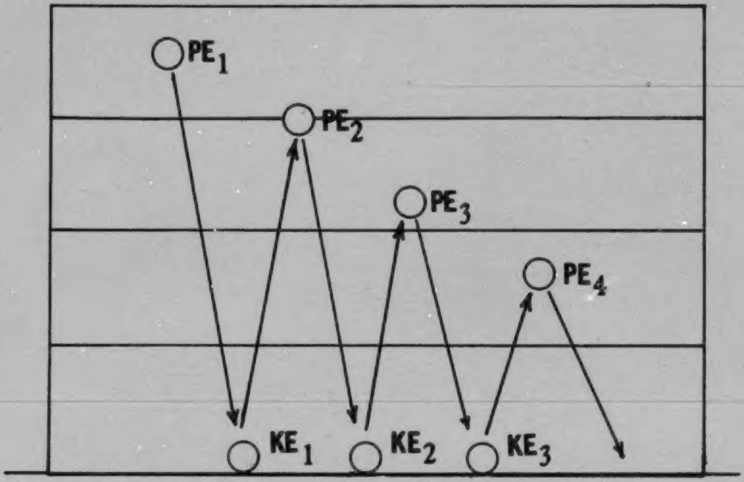
ALLOCATION OF TIME:

The children will need 1-1/2 to 2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. You might start the Activity by having one child lift the hollow rubber ball to the highest position he or she can reach and then drop it in front of the ruled wrapping paper. As the ball bounces, generate discussion along the following lines:	If the children have not had the experiences in Grade 5, Minisequence II--where concepts related to work (in the mechanical sense), kinetic energy, and potential energy are developed--you may want to present a telescoped version of Activities 2 through 5 before beginning the work here. Even if they have had these experiences, it would be wise to review them.

TEACHING SEQUENCE	COMMENTARY
• What had to be done to lift the ball?	The child had to exert a force on it, through a distance, thereby doing work.
• What kind of energy did the ball have just before it was dropped?	Potential energy (energy of position).
• How much potential energy did it have?	An amount just equal to the work that was done on it to raise it to that height.
• What happens to this potential energy as the ball falls?	Part is converted to kinetic energy (energy of motion).
• How much potential energy does it have when it strikes the floor?	None (with respect to the floor); all the potential energy (PE) has been converted to kinetic energy (KE). The kinetic energy is at a maximum just before it strikes the floor.
• What happens to the energy as the ball rebounds?	It is converted back to potential energy as it moves up and away from the floor.
Continue the discussion until the children show that they understand the conversion of potential energy to kinetic energy and back.	
A second child should now be designated to call out the height to which the ball returns after each bounce.	Have the child practice observing the ball against the ruled paper and decide upon some system of interpolating between lines, say to the nearest half division.
Distribute a sheet of graph paper to each child. Ask the first child to drop the ball again and have the children record the different heights to which the ball bounces as the second child calls out the readings. Afterward, each child should make a graph of height plotted against the	The vertical axis can be labeled "Height of the Ball" and

TEACHING SEQUENCE	COMMENTARY
number of bounces.	the horizontal axis can be labeled with the number of the bounce: first bounce (1), second bounce (2), etc. The graph will be useful when comparing the bouncing of this ball with others in Section 3.
Have the children compare the potential energy at the top of each successive bounce.	It should be apparent to them that the height, and therefore the potential energy becomes progressively less.
The cycle of energy changes should be emphasized in discussion--from PE at the top of each bounce to KE at the floor, as shown in the diagram.	



Why does the ball not return to the same height after each bounce? What happens to the energy?	Some children may recognize that this is because of friction during collisions with the floor, and that some of the energy is converted to heat. However, do not press for definitive conclusions at this time, but go on to the next Section, where a clue to the losses is provided.

TEACHING SEQUENCE	COMMENTARY
	Leave the ruled wrapping paper on the wall for use in Section 3.
2. See that each child has a pair of pencils and a rubber band. Have them begin by holding one end of the rubber band in each hand and touching the center of the band to the face just above the upper lip. Then have them suddenly stretch the hand and again touch it to the face above the lip.	The part of the face between the nose and upper lip is very sensitive to slight temperature differences. However, some practive may be needed to sense the change in temperature.
• What do you observe?	They should find that the rubber band feels warmer after stretching it.
• Why does the rubber band get warmer?	Work must be done on the band in order to stretch it. Some of this work is apparently changed to heat energy.
While holding the stretched rubber band in contact with the face, have the children suddenly relax the band.	
• What do you observe this time?	They should find that the rubber band feels cooler.
• Why should it get cooler?	Some children will probably point out that the energy that was put into the band when it was stretched must be removed as thermal energy when it relaxes, resulting in a cooling of the band. This is an acceptable explanation.
Now show the children how to compare the temperatures of the two pencil erasers by touching them briefly to the same sensitive area on their faces.	To avoid warming the eraser with their hands, the children should hold the pencils near the opposite, unsharpened end.
The children can keep one pencil for comparison while they	They should avoid pounding the

TEACHING SEQUENCE	COMMENTARY
pound the eraser end of the other pencil on their desks as hard and as rapidly as they can. After a few minutes they can again compare temperatures of the erasers by touching them both briefly above their upper lip.	eraser on a metal desk top or other thermally conductive surface. If necessary, place a piece of cardboard on the surface so that any heat energy produced by the pounding will not be conducted away. The children should notice a small increase in temperature in the pounded eraser. Some children who cannot pound very vigorously may not be able to detect much difference. They could work with others who are stronger.
The remainder of the Activity should be devoted to a discussion of the temperature rise within the system:	
• What caused the temperature rise?	The children should recognize that the pounding produced heat energy, because of the rise in temperature. (See Activity 4 of Minisequence IV in Grade 5 for an introduction to the idea of the transformation of kinetic energy to heat energy.)
3. Remind the children that when they were observing the bouncing ball, it bounced back with less energy each time. What kind of energy did it have just before hitting the floor? Wasn't this the same kind of energy the moving pencil had? In this way try to associate the production of heat energy with the loss of kinetic energy after each collision.	Note: Before the pencil hit the table, it was in motion; hence it possessed kinetic energy. When it collided with the table it "lost" this kinetic energy. On each collision its kinetic energy is converted to heat energy, which can easily be detected. In the case of the bouncing ball, too little heat energy is produced throughout too large

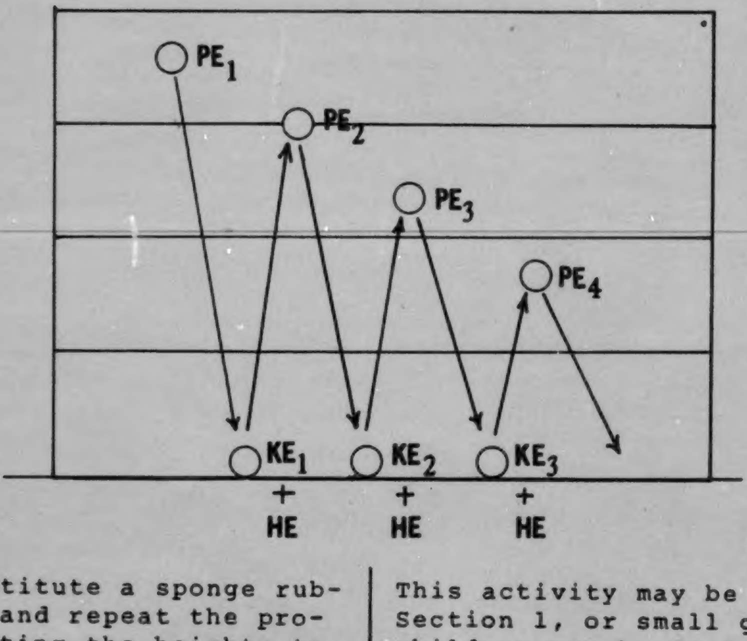
TEACHING SEQUENCE

Again bounce the hollow rubber ball in front of the wrapping paper. Ask the children what they now think happens to the energy "lost" during the first bounce, the second bounce, etc.

COMMENTARY

a ball for the rise in temperature to be detected. Nevertheless, this Activity should provide a basis for children to infer that what happens during collisions of the eraser also occurs during other collisions, such as with the bouncing ball, in which a temperature rise cannot be detected. Note that both the eraser and the ball are made of similar material. However, this is true of any material in which internal friction can take place.

They have had experiences which should now make it possible for them to understand that heat energy was produced when the ball hit the floor. The schematic drawing might be used again with heat energy (HE) included in the sketch.



Next, substitute a sponge rubber ball, and repeat the procedure, noting the heights to

This activity may be done as in Section 1, or small groups of children may be designated,

TEACHING SEQUENCE	COMMENTARY
which it returns after successive bounces. Refer to the graph drawn previously showing the heights to which the hollow rubber ball bounced. Place the new data on the same set of axes, using a different color.	each group being given one of the balls and instructed to gather its data separately.
• Does this ball lose more or less energy at each bounce than the first one?	The children should be able to answer this question by comparing the heights which the two balls attain after the same number of bounces. The one that rebounds higher has lost less energy, of course.
Repeat the entire procedure with a ping pong ball, and then with a "Superball," asking the same questions each time.	A "Superball" will exhibit the least loss of energy, i.e., will rebound higher than the other balls. In technical terms, the collision between this ball and the floor is more "elastic" than the others. Because of its construction, it deforms the least when bouncing and loses the least energy.
Now change the surface on which the ball bounces. Drop the "Superball" on the piece of carpeting and have the class observe its behavior, as before.	The ball will not rebound as high, but now it is because the carpet "absorbs" some of the energy as it deforms, changing it to heat.
• Could a "Superball," or any ball on its own, ever bounce back to a greater height than that from which it was dropped?	The children should be able to conclude that this would violate the principle of conservation of energy.
• How could it be made to bounce higher?	If they respond by suggesting that the ball be thrown at the floor, develop with them the understanding that this means giving the ball more energy to begin with.

TEACHING SEQUENCE	COMMENTARY
• What would happen if the ball were dropped and trapped in a container without being allowed to bounce?	The children should conclude that the temperature of the container must increase, since the mechanical energy of the ball would have disappeared.

Activity 2 The Inefficient Pulley

The purpose of this Activity is to demonstrate "losses" of energy in another kind of mechanical system--the simple pulley--and show that these losses are also due to friction in the system. A pulley can be simply a device to change the direction of an applied force conveniently. One example is raising an object upward by pulling downward on a line which is looped over a rod, as is the case here. However, the pulley that will be used is inefficient. There is considerable friction in the system, which causes substantial mechanical energy losses in the form of heat energy. Thus a greater amount of work must be done to get an object up to a specific height--that is, to increase its potential energy by a given amount--as compared with the work done in simply lifting the object to that same height.

MATERIALS AND EQUIPMENT:

plasticene modeling clay (optional)

For each pair of children:

1 spring scale, 1/2-lb (250-gm) capacity, such as Ohaus (Cenco) model 5405, or 1-lb (500-gm) capacity, model 5505

1 ball, lead, 4-oz (120-gm) or 2-oz (60-gm), with eye for attaching fishing line

1 section of nylon fishing line, 3 feet long

1 ruler, 30-cm

1 nail, about 4 in. (10 cm) long

the unsharpened pencils from Activity 1

PREPARATION FOR TEACHING:

Other than gathering the necessary materials, no special preparation is necessary.

ALLOCATION OF TIME:

The children will need only about an hour to complete this Activity, excluding the time necessary to review concepts introduced in Minisequence II of Grade 5.

TEACHING SEQUENCE	COMMENTARY
1. Start the Activity by having each pair of children attach one end of a nylon line to a lead ball and the other end to a spring scale.	A triple knot is probably a good idea because nylon line can be slippery.
Lower the spring scale until the ball rests on the table top (or floor). Ask the children how they could increase the ball's potential energy.	At this point in the sequence, they will probably suggest lifting it.
• What is the force needed to lift the ball called?	Its weight.
Suggest that they calculate the work done when the ball is lifted through, say, 10 cm.	For example, if the ball is lifted a distance of 10 centimeters with 60 gram-force units, the work done on it can be expressed as 10 x 60 or 600 gram-force centimeters, or simply 600 work units. This number represents the added potential energy of the ball with respect to the table top. In Activity 3 of Minisequence II in Grade 5, the children were introduced to the concept of work as a product of force times distance (F X D). Again, you may need to review this concept with the children at this time.
	Note: If the spring scales are calibrated in grams, the existing unit scale can be used or it can be covered with masking tape, and any arbitrary unit scale can be marked on the tape. Strictly speaking, a

TEACHING SEQUENCE

COMMENTARY

gram is a unit of mass rather than force, although it is often used as a force unit, as with spring scales. This difficulty can be avoided simply by referring to the divisions on the scale as *gram-force units*. The distance the ball is lifted can be measured in centimeters with their rulers.

Put the following headings on the chalkboard and ask each team to write them on a sheet of paper.

Trial	Distance Lifted in cm	Gram-Force Applied	Units of Work
1			
2			

Each team should then record the data for this first trial under the appropriate headings.

2. Next, ask one member of each team to hold the nail by both ends. The other member should loop the nylon line over the nail so that pulling downward on the spring scale raises the ball. Starting with the ball on the floor or table top, they should pull smoothly down on the scale and measure the force now required to lift the ball.

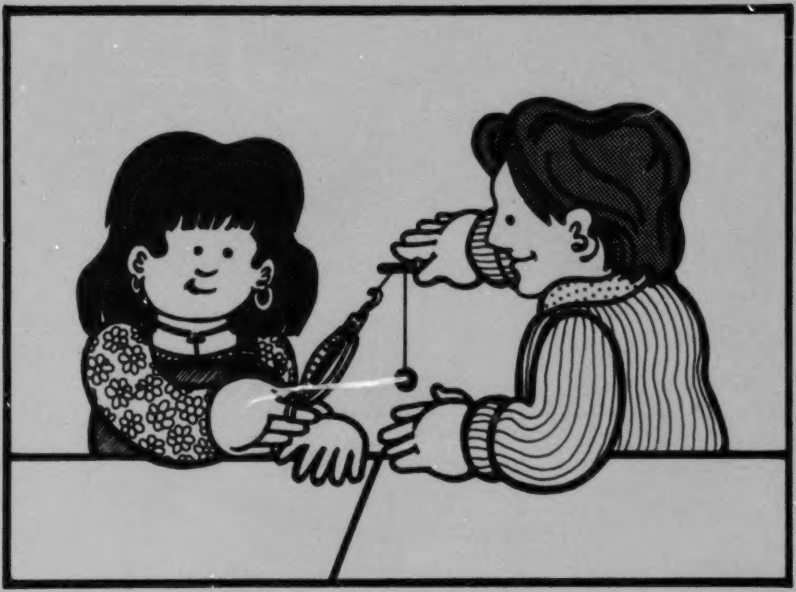
The force required should be considerably greater than before.

Ask them to lift the ball this way a distance of 10 cm again and record their data under the headings for Trial 2.

- Can the difference found between the two trials be due to pulling upward in the first trial and downward in the second?

This may provoke some discussion. They will find later that it is not the direction but the rubbing between the string and the nail that causes

TEACHING SEQUENCE	COMMENTARY
	the difference.
• How does the potential energy of the ball compare after it was lifted in each trial?	Since the ball was at the same height each time (10 cm), the potential energy was the same.
• How could you prove that the potential energy was the same in both cases?	Try to focus the discussion on the meaning of potential energy, i.e., the amount of mechanical work the ball can do: for instance, suppose the ball were dropped from the 10-cm height onto a flat piece of soft clay, forming a depression in the clay. Would this depression be the same each time? The children should conclude that since the ball would be dropped from the same height each time, it should do the same amount of work on the clay. Hence it had the same



TEACHING SEQUENCE	COMMENTARY
	potential energy each time. You may wish to have some of the children actually try this experiment.
Now ask the children to refer to their recorded data and compare the amount of work needed in each of the two trials to increase the potential energy of the ball by the same amount.	It should be obvious that more work was required in the second trial. By now, the children probably will be able to attribute this to friction. Nevertheless, they should go on to the next trial before reaching any final conclusions.
Have the children wrap the nylon line another full turn around the nail and repeat the experiment, recording their data under Trial 3.	
• How much work is required to raise the ball 10 cm this time?	Since more line is rubbing on the nail, the friction has been increased, and they should find that still more work is required to raise the ball 10 cm.
• Why do you think more work was necessary each time?	A greater force has to be exerted to raise the ball the same 10 cm. At this point it should be evident that (a) it was not the change in direction of the force that caused the difference between Trials 1 and 2, and 2 and 3, and (b) the extra work was required because of the rubbing action of the line against the nail.
Ask the children if they can identify what kind of energy this work of rubbing produced:	
• From your recorded data, how many extra work units were needed to lift the ball each time the nail was in the system? What form of energy do you think the extra work produced?	By now, it may be suggested that the extra work produced heat energy. More heat energy

TEACHING SEQUENCE

Ask them what happens when they rub their hands or two pieces of wood together. They will know that the surfaces get warmer. Thus, they should understand that friction produces heat energy.

- If heat energy is produced as a result of the line rubbing on the nail, how could you test for it?

Suggest that they try the following: One child can make two or more turns around the nail with the nylon line. Then, holding one end of the line in each hand he or she can pull it back and forth, keeping it fairly taut.

At this point, you might want to remind them of their study of the bouncing ball in Activity 1. They observed energy losses in that instance also and associated them with the production of heat energy when the ball collided with the floor. Were the energy losses in the bouncing ball also the result of friction?

COMMENTARY

would then have been produced in Trial 2 than in Trial 1 and more in Trial 3 than in Trial 2.

Frictional force was introduced in Grade 5, Minisequence II.

Some children may wonder whether the heat energy produced by friction could be felt as a rise in temperature of the nail.

Very quickly the nail will begin to feel warm. With a vigorous "puller," it will become so hot that the child holding it will soon drop it!

There may be some disagreement about this because the children may not associate bouncing with friction in the same way that they associate rubbing with friction. If so, ask them what they observed when they bounced the erasers against the table top. Then ask what they think they would observe if they *rubbed* the erasers on the table. (Rubbing erasers on the table top will also produce a noticeable increase in

TEACHING SEQUENCE	COMMENTARY
	temperature.
	Both rubbing and bouncing (or pounding) involve friction. In the case of the bouncing ball, it is largely internal friction caused by deformation of the rubber. The same is true of the stretched rubber band.
Finally, summarize the Activity by considering the work that must be put into a system in order to overcome friction and increase the potential energy of an object such as the lead ball:	
WORK INPUT = ADDED POTENTIAL ENERGY + HEAT ENERGY	As indicated in Activity 1, it is always assumed that an object has some potential energy. For instance, the ball when it is still on the table has potential energy with respect to the floor. Its potential energy is increased if it is raised to a higher position.
The larger the amount of friction in a system, the greater the loss of energy in the form of heat energy and consequently the greater the amount of work that must be put into the system in order to increase the potential energy of the object by a set amount.	In the next Activity the children will study the frictional effect further and investigate the influence of lubrication on the work required to increase the potential energy of an object by a given amount. The lead balls and attached fishing line should be set aside for this purpose.

Activity 3 The Inclined Plane

In the previous Activity it was found that different amounts of work had to be expended in order to raise a ball to the same height, depending upon how much friction was encountered (the line rubbing against the nail). An inference was drawn that the ball had the same potential energy each time, regardless of the amount of work put into the system to achieve it because, if dropped from that height, the ball could be expected to do only a fixed amount of work independent of its past history. But if different amounts of work were done to raise it to the same height, what became of the extra work? Actually, the same amount of work was done each time on the ball--the rest was done on the line and nail, reappearing as thermal energy.

The present Activity makes uses of a simple mechanical system, the *inclined plane* (ramp), to provide further evidence that when frictional effects are reduced, the work done to raise an object to a given height--and the potential energy it acquires as a result--does not depend upon the path taken, but only upon the final height. The Activity is divided into two parts, the first dealing with objects exhibiting appreciable frictional effects and the second with the same ball used in the preceding Activity.

MATERIALS AND EQUIPMENT:

masking tape

1 tube of powdered graphite*

1 box facial tissues, or paper towels

1 roll of aluminum foil

For each pair of children:

1 flat ramp 60 cm (2 ft) long; e.g., a piece of stiff corrugated cardboard

1 small book about 4 in. by 7 in. by 1 in. (10 cm by 18 cm by 2.5 cm) or other flat-sided object

light string, about 1 ft

1 ruler, 30-cm

1 spring scale, from Activity 2

1 lead ball and attached fishing line, from Activity 2

2 copies of Worksheet VI-1

2 copies of Worksheet VI-2

*Graphite can be messy, so you may wish to substitute another dry lubricant, such as silicone spray lubricant.

PREPARATION FOR TEACHING:

Set up a sample ramp as shown in the sketch on page 419. Books or any other convenient objects may be used to support one end of the ramp about 25 cm above the other end. This will show children how the equipment is to be arranged and will enable them to observe special techniques to be used when working with it.

Wrap the books to be slid up the ramps with paper and tape it in place. This will keep them from being soiled by graphite later in the Activity. Also, run off sufficient copies of Worksheet VI-1 and VI-2.

ALLOCATION OF TIME:

The children will need about 1-1/2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. As a brief review of previous Activities, first pull the book on a horizontal surface with a spring scale. Calculate the work done with the children. Again this would be the product of the force, as represented on the scale, and the distance through which the book was pulled.	Show the children how to tape a short loop of string to the end of the book to provide a means of attaching the spring scale. The string should not be wrapped around the book (like a present), because the string will interfere with contact between the surfaces of the book and the ramp.
Then ask the children to	Their experience in the previous

TEACHING SEQUENCE	COMMENTARY
suggest some ways of increasing the potential energy of the book.	Activities should lead them to suggest lifting it. Some may also suggest pushing the book up the ramp. While both methods are satisfactory, concentrate initially on the suggestion of lifting the book straight up from the floor.
At this point, all equipment for this Section of the Activity, except the graphite, should be distributed. Teams of two children can be assigned to assemble the ramps. First they should cover the surface of the cardboard with a fresh, smooth piece of aluminum foil and tape it down on the back of the cardboard. One end of the cardboard can then be propped up on a pile of books or other suitable objects to make a ramp. In each case the elevated end of the ramp should be approximately 25 cm above the floor.	The surface of the aluminum foil should be as wrinkle-free as possible.
• How much work is done on the book when it is lifted vertically to the top of the ramp?	
First the children can measure the vertical distance between the floor or table top and the tip of the ramp and enter this value in the appropriate space on Worksheet VI-1. Estimations to the nearest centimeter are desirable. Then they should measure the force needed to lift the book and record this value. Because they will later compare the work needed to lift the book with that required to slide it up the ramp to the same height, the children should measure it as carefully as they can. When the force and	By now the children should have no difficulty measuring the lifting force with the spring scale and the distance with a ruler.

WORKSHEET VI-1

Name:

	STRAIGHT UP	ALONG THE RAMP (1)	ALONG THE RAMP (2)
FORCE NEEDED TO MOVE BOOK			
DISTANCE MOVED FROM FLOOR TO TOP OF RAMP			
WORK DONE (F X D)			

TEACHING SEQUENCE

distance data have been collected by each team, the team members should calculate the work done on the book and enter the value on the Worksheet.

Now have the children practice pulling the book up the ramp with the scale so that it moves up slowly at fairly constant speed. When they have learned the technique of pulling the book up the incline, the force should be measured and recorded on the Worksheet. The length of the ramp should also be measured and recorded. With the force and distance known, have them calculate and record the work done in pulling the book to the top of the incline in the second column (2) on the Worksheet.

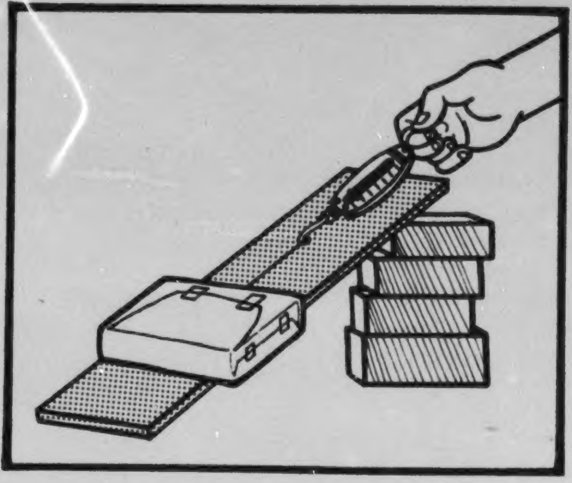
Through the discussion the children should realize that although the paths taken by the book were different, it was raised to the same height in both cases.

- How does the amount of work done in the two cases compare?

While some may assume that the difference in amounts of work is perfectly acceptable, others may point out that in both cases the book was raised to the same height, and therefore the work done on the book should be the same. Ask if they can account for the difference.

COMMENTARY

The pull should be steady, with as little jerkiness as possible, to get the best reading.



Their Worksheets should show that more work was done in pulling the book up the ramp than in lifting it vertically to the same height, despite the fact that the lifting force was less. A sample filled-in Worksheet is shown on page 421.

Remembering the previous Activity, where part of the work put

TEACHING SEQUENCE	COMMENTARY
	into the system was converted to heat energy through friction, they are likely to say that the book "rubbed" against the incline: hence more work had to be done because of friction here also. Be sure the children understand the distinction between the amount of work put into a system and the amount of work done on the object itself.
• How could you slide the book up the ramp so that less work is converted to heat energy?	Probably someone will suggest using a lubricant of some kind.
Show the children how to lubricate the ramps and (wrapped) books using the powdered graphite. This should be done by squeezing a small amount of the powder on a piece of facial tissue or paper towel and lightly rubbing it over the aluminum foil. When the surfaces are well lubricated, have the children repeat the part of the activity in which the book is pulled up the ramp. They need only make a new measurement of the force required, since the distance will be the same. Have them record their data and calculate the work done in the third column (3) on the Worksheet.	The surfaces can also be lubricated simply by wetting them with water, but this is not as good a lubricant as graphite. To distribute the graphite, spray or squeeze a small amount on a tissue for each pair of children. They can then wipe it lightly over the foil themselves. The graphite could also be put directly on the foil and then wiped around. In either case, care should be taken in spreading the powder because it tends to soil the hands and clothing.
• How does the amount of work done on the system compare this time?	When they compare the work done in pulling the book up the lubricated ramp with that required when the ramp was not lubricated, they should conclude that there was less work done and thus less friction in the case of the lubricated ramp. Consequently less work was converted to heat energy. In other words, not as much

WORKSHEET VI-1

Name: Lily

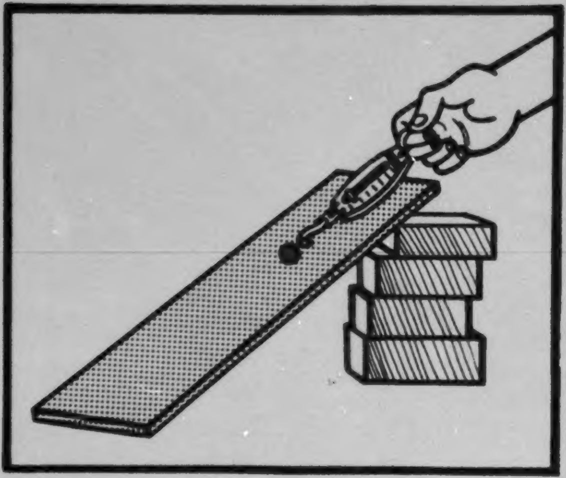
	STRAIGHT UP	ALONG THE RAMP (1)	ALONG THE RAMP (2)
FORCE NEEDED TO MOVE BOOK	250g	210g	140g
DISTANCE MOVED FROM FLOOR TO TOP OF RAMP	25 cm	63 cm	63 cm
WORK DONE (F X D)	6250 work units	13230 work units	8820 work units

TEACHING SEQUENCE	COMMENTARY
	mechanical energy is "lost" when friction is reduced.
• How could the friction be reduced still further?	Help the children to see that if the amount of surface areas in contact with each other was reduced, there would be less rubbing of one against the other and consequently less energy lost as heat.
• What shape object would provide a smaller amount of surface in contact with the ramp?	A sphere, such as a lead ball, would provide a much smaller surface area in contact with the ramp than a flat object like a book.
2. With the ramps still set up, the children should now retrieve the lead balls and attached fishing line which they used in the previous Activity. In each case the long fishing line should be untied from the ball and the ball retied to a short length of string, as with the book. The ball should then be reattached to the spring scale and Worksheet VI-2 distributed.	The wrapped books can be set aside. The fishing line should be saved for use in Activity 4, where it will be used to make a pendulum.
The procedure is identical to that used in Section 1 of the Activity. The children should compare the work needed to pull the ball up the ramp system to a given height with that done on the same ball in lifting it vertically to the same height.	Instead of the book, the children will pull the ball up the ramp, thereby minimizing the effect of friction (the ball is smooth and contacts only a small area on the ramp). In this system only a very small amount of work is converted to heat energy.
	Comparing the work done should reveal that there is a minimal conversion or "loss" of mechanical energy to heat energy when the ball is pulled up the ramp. Once again, help the class to understand that when an object is raised, its gain in potential energy is related only to the vertical distance

WORKSHEET VI-2 Name:

	STRAIGHT UP	ALONG THE RAMP
FORCE NEEDED TO MOVE METAL BALL		
DISTANCE MOVED FROM FLOOR TO TOP OF RAMP		
WORK DONE (F X D)		

TEACHING SEQUENCE



Some children may want to try lubricating the surface of the ramp in order to decrease the friction even further. They should be encouraged to try it. However, pulling the ball up the lubricated ramp will probably not result in any measurable difference in the work done as compared with the unlubricated surface.

Finally, ask the children to imagine that all the frictional losses were removed.

- How much work would then be required to slide the ball up the ramp compared with the amount needed to lift it vertically?

COMMENTARY

through which it is moved, and not to the path taken.

The truly relevant factor is the work done on the ball rather than on the system with which it it may be associated.

The object touches the ramp in too small an area anyhow--theoretically in one point only in the case of a ball. But they will have reduced the friction still further and can again conclude that in the absence of friction there would be no difference in the work required to lift the object vertically and to slide it up the ramp to the same height.

Help them to understand that the work should then be the same in both cases. That is, no work would be converted to heat.

EXTENDED EXPERIENCE:

Some children may be interested in investigating the effect of using sandpaper to increase the friction. They could tape a piece of sandpaper to the bottom surface of the wrapped book and determine the amount of work necessary to pull it up the ramp.

Activity 4 The Ballistic Pendulum

In Activity 3 the children found that by doing work on an object, they could increase its potential energy--that is, raise it above the table top. By applying a force vertically (upward), all the work done went into increasing the potential energy because there was no friction; when the force was applied so as to slide the object up a ramp to the same height (hence the same potential energy), they found that more work was required because of friction between the object and the ramp. They also found that this frictional "loss" could be decreased by lubricating the surfaces, and by inference concluded that in the absence of friction there would be no difference in the work required to lift the object vertically or slide it up the ramp to the same height.

The present Activity deals with the inverse problem, that is, given an object (a pendulum bob) with potential energy, how can it be used to do mechanical work? At one point the children considered what a falling ball could do to a piece of clay. Here, they will find that by allowing the pendulum ball (bob) to swing downwards, the potential energy of the bob is converted to kinetic energy as it swings down. At the bottom, it will be moving most rapidly, hence it has greatest kinetic energy which can then do work: if allowed to strike an object at the bottom of its swing, the bob will cause the object to move through some distance. They will find that the greater the potential energy of the bob (i.e., the greater the height from which it is released), the more work it can do when its energy is converted to kinetic energy.

This Activity, dealing as it does with the conversion of potential to kinetic energy, prepares the class for the next and final Activity, which involves the repeated interconversion of potential and kinetic energy in a freely swinging pendulum.

MATERIALS AND EQUIPMENT:

For each pair of children:

1 4-oz or 2-oz lead ball attached to a 3-ft length of nylon fishing line (as in Activity 2)

1 wooden block about 2 by 2 by 4 in. (5 cm by 5 cm by 10 cm), or other similar flat-sided object

3 30-cm rulers

1 paperbound book or magazine without protruding covers

2 Worksheets VI-3

PREPARATION FOR TEACHING:

A demonstration setup of the apparatus shown on page 428 will help the children to assemble their own. The pendulum is suspended by putting its line through a paperbound book or heavy magazine which does not have a protruding cover. The line should be laid along the spine so that, when the book is closed, the line is held firmly but is easily adjusted. The line should not rub against the pages of the book any more than necessary. For this reason the line should be inserted towards the bottom of the book. The children may find that the line is displaced as part of the reaction when the pendulum hits the block. A piece of tape on the pages next to where the string emerges from the book will prevent this displacement.

Two rulers serve as guides for the block as well as a means for measuring the distance that it moves. When the pendulum is lined up with the block, the two should be barely touching as the pendulum hangs vertically.

Prepare a sufficient number of copies of Worksheet VI-3 (one for each child).

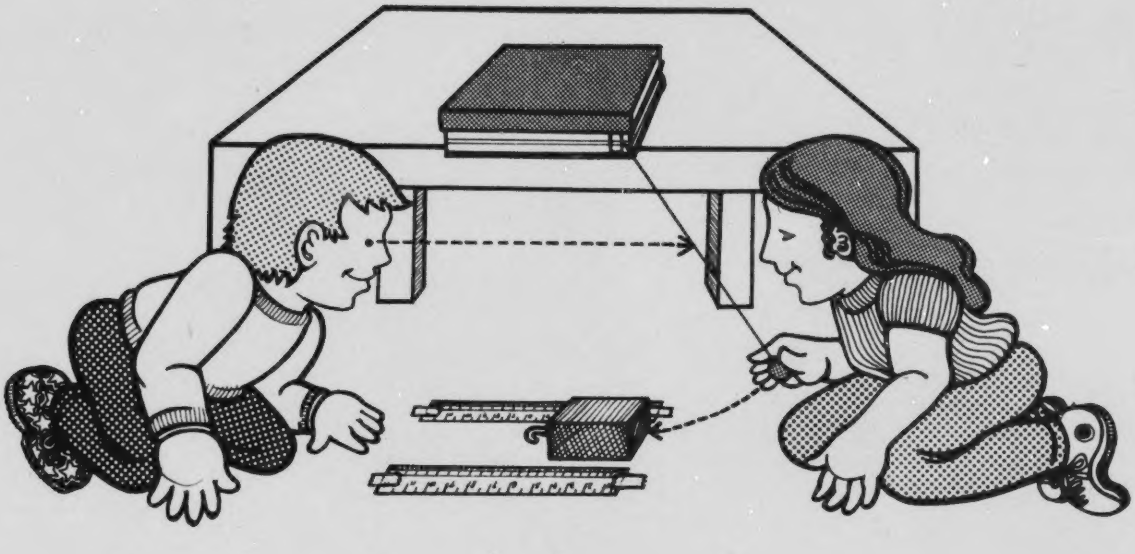
ALLOCATION OF TIME:

The children will need about an hour to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. Have the teams assemble their apparatus. Then begin the discussion by asking how the block can be made to move.	The children probably discovered while setting up their apparatus that the block can be moved if the pendulum bob is allowed to swing and collide with it.
• What must be done to the pendulum bob in order for it to acquire enough kinetic energy to move the block?	They should realize that work must be done to increase its potential energy--and that its potential energy will then change to kinetic energy as the bob is released and starts its swing.

TEACHING SEQUENCE

COMMENTARY



The children should practice lifting the ball, keeping the line taut, and then releasing the ball, until they are able to hit the end of the block squarely.

At this point, distribute a Worksheet to each child. The ball should first be pulled back from the block until it is 5 cm higher (d = 5 cm) than its position at rest and then released to collide with the block. The distance the block moves should then be measured.

The ball should be pulled straight back without twisting the string.

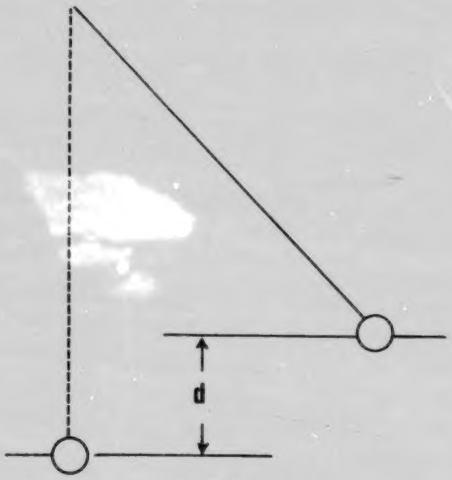
Note that the distance, d, is measured vertically as shown in the illustration on page 430. The third ruler can be used to make the measurement. They might find it even easier to make a free standing chart with 5, 10, 15, 20 and 25 cm markings on it and simply pull the pendulum bob to the appropriate height each time.

WORKSHEET VI-3 Name:

TRIAL	HEIGHT OF BOB BEFORE RELEASED	RELATIVE POTENTIAL ENERGY BEFORE RELEASED	RELATIVE SPEED OR KINETIC ENERGY AT BOTTOM OF SWING	AVERAGE DISTANCE BLOCK MOVED

TEACHING SEQUENCE

COMMENTARY



Help the children to realize that work is done on the block when the bob strikes it and sets it sliding across the floor.

- Why is work required to move the block along the floor?

Suggest that the children repeat the experiment several times so that the average distance the block moves can be determined and recorded on the Worksheet.

They may be reminded of their work with the marble and cup-sled in Minisequence II of Grade 5, if they had those experiences.

Because of friction between the bottom of the block and the floor. Note that the potential energy of the block remains unchanged. Hence all the work is expended in overcoming friction, i.e., is converted to heat energy.

It is suggested that at least three measurements be made for each height of the pendulum and then averaged. Any measurements where the block moved sideways and bumped the rulers because it was not hit squarely should be discarded. Also, the children should be sure the starting position of the block with respect to the rulers is the same for all trials. Since some rulers do not start at 0, you might consider placing the block at 1 and reading the

TEACHING SEQUENCE

- How fast was the bob moving just before collision?

This qualitative assessment of its speed should be entered on the Worksheet either now or after comparison with the speed in Trial 2.

Ask the children to consider the potential energy of the bob at the time it was released. They should recall, from the preceding Activity, that the added potential energy is directly related to the vertical height through which it was raised and not on the path taken by it. A qualitative description of the potential energy of the bob before release should also be entered on the Worksheet either now or later.

- What is the potential energy of the bob at the bottom of its swing?

The children should now release the bob from a height 10 cm above its rest position. Have them enter on their Worksheet the new average distance the block moves. If necessary, discuss again the

COMMENTARY

distance it moves from there. As in Grade 5, it would be helpful to check the readings by placing a card against the face of the block and across one of the rulers. Read to the nearest 0.1 cm.

The children should eventually realize that the speed of the bob, and hence its kinetic energy, was relatively small. You may want to withhold discussion of the relative kinetic and potential energy of the bob for each trial until the experiment is completed. They should then be able to make the comparisons necessary to see that the greater the height of the bob before it was released; the greater its potential and kinetic energy.

Qualitatively, when the bob is raised only 5 cm, its potential energy is small, like its kinetic energy at the bottom of its swing.

The children should realize that while the bob still has potential energy with respect to a surface below it (if the fishing line were cut, the ball would fall and could do work), the system has reached its lowest possible potential energy.

WORKSHEET VI-3

Name: Lily

TRIAL	HEIGHT OF BOB BEFORE RELEASED	RELATIVE POTENTIAL ENERGY BEFORE RELEASED	RELATIVE SPEED OR KINETIC ENERGY AT BOTTOM OF SWING	AVERAGE DISTANCE BLOCK MOVED
1	5 cm	small amount	small amount	3.2 cm
2	10 cm	more than trial 1	more than trial 1	6.5 cm
3	15 cm	more than trial 2	more than trial 2	10.4 cm
4	20 cm	more than trial 3	more than trial 3	13.8 cm
5	25 cm	greatest amount	greatest amount	17.8 cm

TEACHING SEQUENCE	COMMENTARY
potential and kinetic energy of the system before the children enter their qualitative assessments of these quantities on the Worksheet.	
Have the children continue the procedure, releasing the ball from 15 cm, then 20 cm, and finally from 25 cm above the rest position, recording all data on their Worksheets.	They should now easily see that as the potential energy of the bob is increased, its kinetic energy when it reaches the bottom also increases and it moves the block farther. A sample filled-in Worksheet is shown on page 432.
2. Now use the demonstration apparatus to introduce the following line of discussion: Remind the children that they have information about the energy of the bob at the top and bottom of its swing; suggest that they now consider the energy of the bob as it moves through its curved path.	All that will be needed for this purpose is the pendulum and its support. The block and guide rulers can be set aside.
Move the bob through its arc so that it is some distance above its rest (lowest) position, as before. Ask the children to describe the potential and kinetic energies of the bob while it is held in this position.	They should realize that the bob has gained potential energy but that since it is not moving, it has no kinetic energy.
Now move the bob through its arc to a lower position and hold it there.	
• How does its potential energy now compare with what it had in the higher position?	It must be less. It is important that they recognize that the bob loses potential energy as it moves to a lower position.
• What is its kinetic energy?	Zero, since it is again motionless.
Finally, let the bob hang vertically, supported only by the string.	

TEACHING SEQUENCE	COMMENTARY
• How much potential energy does it now have?	Zero, since this it the lowest level the bob can attain. It has no P.E. with respect to this level.
Again, move the bob to the first height used in the demonstration and ask the children to predict what will happen to the bob when it is released.	Some may suggest tht it will gain speed and start to swing; others may say that it will gain K.E. Both answers are correct, but if the latter is not put forward, ask them to describe the K.E. of the bob as it starts to move through its arc.
• Where is the P.E. a maximum?	At the top of its path.
• Where is it least?	At the bottom.
• Where is the K.E. a maximum?	At the bottom of the swing where it is moving most rapidly.
• Where is it zero?	At the top, prior to release, where it is not moving at all.
Help the children to understand the energy changes that occur during the swing--that as the bob moves through its arc, it loses P.E. but gains an equivalent amount of K.E. (if there are no losses due to friction). At any point in its swing, assuming that energy is conserved, the sum of the potential energy and kinetic energy should equal the original potential energy of the bob.	Their past experiences with conservation of heat energy should help them to grasp this fairly readily. If they are able to reach this conclusion, they clearly understand how energy conservation may be applied to an ideal mechanical system. The next Activity will give them some practical experience with this concept.

Activity 5 The Swinging Pendulum

In the previous Activity the children studied the mechanical energy conversions that occurred as the pendulum swings through part of an arc (actually half its total swing). It was interrupted by colliding with a block at a point when its kinetic energy was at a maximum. In the present Activity they will study the pendulum as it makes complete swings in each direction, observing the energy changes that occur throughout its motion, and seeking to account for any energy losses. At the end of the Activity they will perform a simple experiment, first described by Galileo, which should help to reinforce their acceptance of the principle of conservation of energy. This experiment, known as the Galilean Pendulum, is embodied in the COPES logo on the cover of the Teacher's Guide.

This is the last Activity in the COPES program. It seeks to bring together all the experiences the children have had on the concepts of energy and energy conservation, and to apply these to a mechanical system that is as nearly ideal as possible--the simple pendulum. The children will find in this Activity that their earlier inference regarding the effect of reducing friction in a system is borne out; mechanical energy appears to be more nearly conserved. Extrapolating mentally from a nearly ideal system, such as the pendulum, to a perfectly ideal system then becomes easier for them. If mechanical energy is nearly conserved in a swinging pendulum, it follows that if frictional effects are sufficiently reduced in any mechanical system, that system should exhibit nearly perfect energy conservation. Such extrapolations from experience, as is pointed out in the introduction to the COPES program, are characteristic of science, and particularly of the great ideas of science--the conceptual schemes that form its cornerstone.

MATERIALS AND EQUIPMENT:

For each pair of children:

1 4-oz or 2-oz lead ball with a 2-ft length of fishing line attached

1 paperbound book or heavy magazine without protruding cover

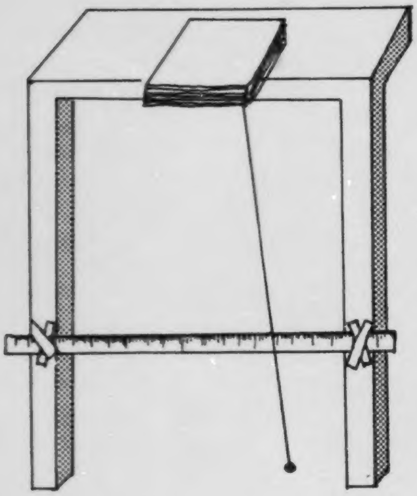
1 meter stick, or yard stick

2 rulers, 30-cm

masking tape

PREPARATION FOR TEACHING:

A demonstration apparatus set up almost the same as in Activity 4 (and shown in the illustration) will be helpful to the children in assembling their own apparatus.



The pendulum pivot at the book should extend about 8 cm out from the desk or table. The nylon line should be approximately 60 cm long. Use tape to mount the meter stick on legs of the desk or table, in a horizontal position about 25 cm above the pendulum bob. Use a ruler to measure the height of both ends of the meter stick above the floor to make sure they are the same, i.e., the meter stick is exactly horizontal.

ALLOCATION OF TIME:

Allow about 1-1/2 hours to complete this Activity.

TEACHING SEQUENCE	COMMENTARY
1. After the teams have assembled their apparatus, begin the Activity with a brief review of the earlier Activities in this Minisequence, particularly of the concepts of work, potential energy and kinetic energy.	The children can again work in teams of two.
The children should recall that the potential energy of an object is a measure of its ability to do work because of its position, while	In the previous Activity the children observed that work was done on a ball (the pendulum bob) to increase its P.E. when it was lifted through an

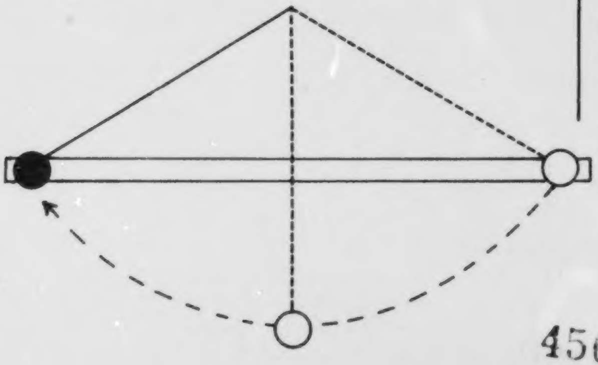
TEACHING SEQUENCE

the kinetic energy of an object is its energy of motion.

- What changes occur in the potential and kinetic energy of the ball during its downward swing?

To begin the actual investigation, suggest that each team designate one member to observe the bob after the other releases it from an elevated position. Ask the child who will release the bob to lift it through an arc as high as the meter stick and hold it there.

When the observer is ready, the bob should be released. Ask the observer to note the height to which the bob rises on the opposite side of the arc.



COMMENTARY

arc and held above its rest (lowest) position. They should also recall that the bob lost P.E. and gained K.E. when it was released. At the bottom of the swing its P.E. was at a minimum, while its K.E. was at a maximum. They observed that work was done when the bob collided with a block at the bottom of its swing and moved it against friction. In shorthand form, this could be expressed as follows:

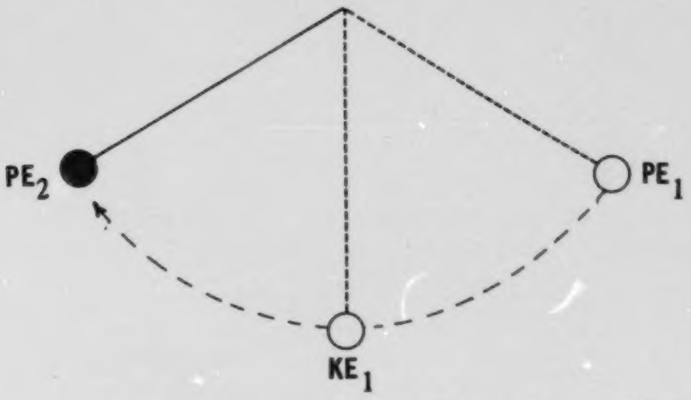
Work ⟶ P.E. ⟶ K.E. ⟶ Work

They should realize that the ball's potential energy is converted to kinetic energy while the ball moves downward through its arc.

For the present, the children should disregard the height to which it rises in subsequent swings.

If the ball swings without interference, they should find that it reaches practically the same height at the opposite side of the first swing as that from which it was released.

TEACHING SEQUENCE	COMMENTARY
On the next trial, the observer should catch the ball when it reaches its maximum height at the opposite end of the arc and hold it there. Ask the children to describe the energy of the ball at this point.	They should realize that it now has P.E. but no K.E.
See if they can describe the energy of the ball at the bottom of the arc, where it was moving most rapidly.	They should understand that at this point it had no P.E. (relative to its rest position) but that it had considerable K.E.
Ask them if they can explain how the ball, now being held at the opposite end of its arc, acquired its present potential energy. That is, where did the P.E. come from? The discussion should develop the idea that its kinetic energy at the bottom of the arc was converted to potential energy as it moved up to the top of the arc on the opposite side. Sketch the illustration below on the chalkboard.	

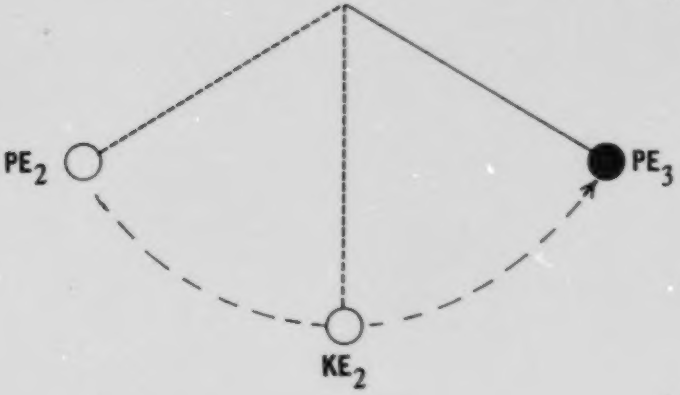


• How does the amount of P.E. the ball had at the beginning of the swing (PE_1) compare to that at the end of the swing (PE_2)?	Since both positions are nearly the same height above the rest position, they should conclude that the P.E. is approximately the same at both points.
If they do not conclude that	

TEACHING SEQUENCE

the ball has the same P.E. in both positions, develop the idea that since the two heights are the same the P.E. must be the same.

Now ask the children to release the ball from the opposite end of the arc (the PE_2 position) and observe the height to which it rises on the other side. Again, they should catch and hold it when it reaches its maximum height.



A discussion similar to the previous one for the first swing should focus on the source of the new P.E. (PE_3) acquired by the ball. Again, ask the children to compare the amounts of P.E. at the beginning and end of the arc. Continue to develop the idea that kinetic energy (KE) was changed to potential energy (PE).

COMMENTARY

That is, it would take the same amount of work to raise it to the same height even though at a different end of the arc.

They should find that it again rises to about the same height from which it was released.

In developing their understanding of these energy conversions, it may be helpful to assign an arbitrary value to PE_1. For instance, ask them to imagine that the potential energy of the ball in its original position (PE_1) is 100 units. Then ask them to estimate its potential energy at the other end of the arc (PE_2). They should understand that it will have nearly the same amount at the other end,

TEACHING SEQUENCE

A chalkboard illustration of one complete swing should help to convey the idea of the continuous nature of the energy conversions in a swinging pendulum:

$$PE_1 \longrightarrow KE_1 \longrightarrow PE_2 \longrightarrow KE_2 \longrightarrow PE_3 \longrightarrow$$

Throughout the discussion the children should be helped to recognize that in the interconversions between potential and kinetic energy, practically no energy is "lost" as the pendulum swings. The following chalkboard illustration may be helpful.

$$PE_1 = KE_1 = PE_2 = KE_2 = PE_3 = \ldots$$

When it seems that the children understand the energy conversions, they should lift the ball to other heights to see whether they get the same results. They can change the height of the meter stick and continue to use it as a convenient reference line.

2. When the children have had simple experience with energy conversions as the pendulum traverses a single arc, they should release the ball from a convenient height and allow it to continue swinging without interruption. They will notice that the maximum height to which it rises during each swing gradually becomes

COMMENTARY

say 98 or 99 units. They should also understand that it can never have more--i.e., PE_2 can never be more than PE_1--unless the pendulum bob is pushed as it is released. Continue the questioning and discussion to develop the idea that the K.E. of the ball at the bottom of its path, where it was moving fastest, was also very close to 100 units.

Some children may say that one can not have a "perfect" system, i.e., some energy must be lost. This is true, of course, and makes a nice transition to the next Section, but suggest that for the time being they assume these losses are negligible.

Observations may be difficult if the meter stick is mounted too low or too high. The region from about 15 cm above the bottom of the swing to about 15 cm below the pendulum support is suitable.

TEACHING SEQUENCE	COMMENTARY
progressively less. As they report their observations, encourage them to refer to the potential energy of the ball rather than to its height.	The ball appears to be losing some potential energy on each successive swing; i.e., some of its energy appears to be "disappearing."
• What would you infer, then about the kinetic energy at the bottom of the swing?	They should be able to infer that the kinetic energy, too, must be diminishing.
Ask the children if they can explain why energy appears to be going out of the system. If no one mentions friction at the suspension point, call their attention to what is happening there.	Most of them should quickly realize that the nylon line is rubbing and bending (therefore there is friction), and will recall from their former experiences that heat energy is produced under such conditions, even though they may not be able to measure it.
Help them to understand that some of the energy in the swinging pendulum is being converted to heat energy on each swing, and thus the pendulum is gradually losing potential energy. The overall energy conversions can be diagramed in the following way:	

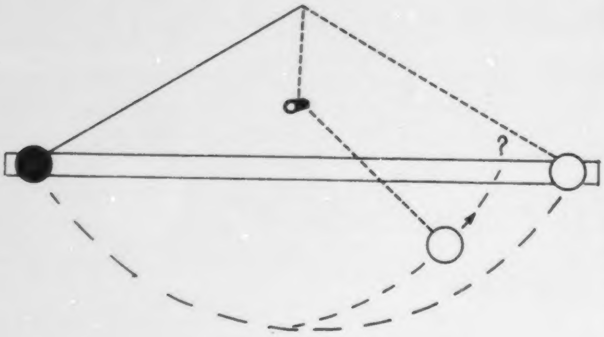
$$\begin{tikzcd}
 & HE_1 & & HE_2 & & HE_3 & & HE_4 & \\
PE_1 \arrow[rr] \arrow[ur, bend right] & & KE_1 \arrow[rr] \arrow[ur, bend right] & & PE_2 \arrow[rr] \arrow[ur, bend right] & & KE_2 \arrow[rr] \arrow[ur, bend right] & & PE_3
\end{tikzcd}$$

Mechanical energy comes out of the system and goes into the pivot and string as heat energy with each complete swing back and forth.	The symbolic statement above actually implies that the total energy in a pendulum system is conserved. Although the mechanical energy decreases, the sum of the mechanical energy and heat energy is the same as the original amount of mechanical energy (PE_1).
• Can the heat energy be	Not with their apparatus

TEACHING SEQUENCE	COMMENTARY
detected?	because the temperature change is so small, but with a suitably designed experiment it could be.
Continue the discussion by asking them to imagine what might happen to the swing of the pendulum if the friction at the pivot were greatly increased, and to explain their predicted results in terms of P.E. and H.E.	The pendulum should stop swinging much sooner as more mechanical energy is converted to H.E. in each swing. They may be reminded of the inefficient pulley here.
Finally, ask the children what would happen if it were possible to eliminate friction entirely in this system.	The results of their investigations together with the preceding discussion, should help to convince them that the pendulum would continue to swing indefinitely. In other words, it would be an ideal mechanical system.
3. It should be clear by now that although the pendulum is nearly an ideal mechanical system, the pendulum bob does gradually lose mechanical energy. However, some children may still believe it possible to get more energy out of such a system than was originally put into it. The following simple experiment can be used to test this hypothesis:	
Have the children hold a pencil with its eraser end firmly against the leg of the table or other firm back support behind where the pendulum is hanging, so that the pendulum line just touches it. The pencil should be at some point above the meter stick, as shown in the illustration.	If there is no easily available back support, the pencil, or even a finger, can be held stationary to interrupt the path of the line.
	It may be interesting to the children to know that this experiment was first described by Galileo and is known as the Galilean Pendulum.

TEACHING SEQUENCE

Ask them to lift the ball through its arc to the height of the meter stick, and then to predict the maximum height to which the ball will rise on the other side of its swing when it is released, bearing in mind that the string will now strike the pencil. After the children have made their predictions, they should test them.



The results should be discussed in terms of the initial P.E. of the ball.

COMMENTARY

Some children will predict that the pencil will affect the motion of the pendulum and that it will not rise to the same height on the other side. Others, however, will predict that because the arc will be steeper, the ball will rise higher than if allowed to swing freely. (If it did, this would mean that the bob would have more potential energy at that point than it had to start with.) They will be surprised to find that the ball comes up to approximately the same height from which it was released. You might direct their attention to a chalkboard diagram like the COPES logo on the cover of the Teacher's Guide.

The discussion should be directed toward convincing the children that conservation of energy means that the energy remains the same--it does not decrease. Some of it may be converted to other forms such as heat, but the total remains the same. By implication, it cannot increase unless more work is done on the system.

Materials and Equipment

An alphabetical list of materials and equipment is included for your convenience in obtaining the materials necessary for teaching the Grade 6 sequence of COPES. The list includes the total amount of materials for the Grade 6 sequence. The children can often bring materials, such as marbles and empty baby food jars, from home. Some items--such as paper, pencils, and crayons--will be available in your school. Check also for equipment that may be available from a school science storeroom. Most of the remaining items can be purchased locally in grocery, stationery, drug, photography supply or hardware stores. A few items such as thermometers, balances, magnifying glasses, and some chemicals (see page 459), may have to be ordered from one of the scientific supply houses listed on the last page of this section. The magnifying glass sold by American Science and Engineering (A.S.& E.) with the triple lenses (No. 2400) is recommended. If you are ordering the -20°C to +50°C thermometers from Damon, Macalaster, or A.S.&E., be sure to specify the plastic backing. Some of their thermometers have metal backings which can not be used for the Activities in Minisequence IV. The Macalaster thermometer (No. 2662) has a plastic backing.

Whether you are ordering from a supply house or purchasing items locally, keep in mind that, for convenience, the quantities are for a class of 30 children. If your class is larger or smaller you may want to vary the amount accordingly.

When ordering copper sulfate for use in Minisequences II and III, specify ACS (American Chemical Society) or Reagent grade of the chemical, not technical grade. This substance must be in the form of fine crystals for these Activities, not large clumps. The two anhydrous salts called for can, of course, be ordered directly from a chemical supply house. However, as described in Minisequence II, Activity 3 under Preparation for Teaching, each anhydrous salt can be readily prepared from the respective hydrated crystals by simply heating them in an oven.

Often in COPES particular items of equipment or materials are used in more than one Activity, or Minisequence, or even grade level. Thus the nonconsumable items, and those consumables which are left over, should be stored for possible later use. To help you, the list contains a column indicating the Minisequence(s) and Activity (or Activities) where each item is used.

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
Aluminum foil:		
heavy duty	1 roll	II-2; III-4,5
muffin liners or pieces to form boats, e.g., 7.5 cm by 7.5 cm (3 in. by 3 in.)	100-180	II-1,3; IV-2
regular	2-3 rolls	II-4; IV-7; VI-3
Bags:		
plastic garbage size, 29 cm by 32 cm (11-1/2 in. by 13 in.) 1 gallon (3.7 liters) capacity	35	I-2,4,5; IV-1
plastic sandwich size (optional)	2-4	IV-4
Balances:		
spring scale, pull down, e.g., Ohaus, 250 g (model No. 5405) or 500 g (model No. 5505)	15	VI-2,3,4
student platform, e.g., Ohaus model No. 1200	1-8	I-1,4; III-3
Balls:		
hollow rubber, about 2 in. (5 cm) in diameter	1	VI-1
sponge rubber, about 2 in. (5 cm) in diameter	1	VI-1
Superball, about 1 in. (2.5 cm) in diameter	1	VI-1
ping pong	1	VI-1
lead, 60 g (2 oz) or 120 g (4 oz) with eye to attach a line	15	VI-2,3,4,5
Beakers, heat resistant, 30 ml (1 oz) capacity	30	II-4

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
Books:		
small, about 10 cm by 18 cm by 2.5 cm (4 in. by 7 in. by 1 in.) or substitute	15	VI-3
paperbound (or magazine)	15	VI-4,5
Bulbs, 100 watt	11	I-5
Cardboard:		
boxes, approx. 20 cm by 20 cm by 20 cm (8 in. by 8 in. by 8 in.)	11	I-5
corrugated piece, 8 cm by 18 cm (3 in. by 7 in.)	9 pieces	IV-7
corrugated, 6 in. square (15 cm sq)	60 pieces	V-2
corrugated (for ramp) 2 ft long (60 cm) by about 6 in. (15 cm) wide (wood plank can substitute)	15 pieces	VI-3
index cards, 3 in. by 5 in.	70 or more	I-5; IV-7
shoe box (as ringstand assembly)	1	II-5
square, 6 in. on a side	1 piece	II-1
Cement, two-part epoxy	small tube	II-1
Chemicals, supplies of:		
ammonium chloride (sal ammoniac)	60 g (about 2 oz)	III-4, 5
calcium chloride	125 g (1/4 lb)	III-4; IV-4
cobalt(ous) chloride, hydrated, crystals	125-250 g (1/4-1/2 lb)	II-4; III-1
copper (cupric) chloride, hydrated, crystals (optional)		III-4
copper (cupric) nitrate, hydrated crystals (optional)		III-5

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
copper (cupric) sulfate, hydrated fine crystals (blue vitriol)	450-900 g (1-2 lb)	II-1,2,3; III-1,2,3,4
copper (cupric) sulfate, anhydrous	125 g (1/4 lb)	II-3; III-4
iron (ferrous) sulfate, hydrated crystals	125 g (1/4 lb)	III-1,3
lithium chloride (optional)		III-4
magnesium sulfate, hydrated crystals (epsom salt)	250-450 g (1/2-1 lb)	II-1,3; III-1,4
magnesium sulfate (anhydrous)	125 g (1/4 lb)	II-3
nickel sulfate, hydrated crystals (optional)		II-3
phenyl salicylate (salol)	70 g (approx. 2 oz)	II-1; IV-2
potassium chloride (also available as "salt" substitute)	60-120 g (2-4 oz)	III-4
silver nitrate	10 g (1/3 oz)	III 5
sodium acetate, hydrated crystals	125 g (1/4 lb)	II-4
sodium carbonate, monohydrate (optional)		II-3
sodium sulfate, hydrated crystals (Glauber's salt)	30-60 g (1-2 oz)	III-4,5
sodium thiosulfate, hydrated crystals (hypo)	125 g (1/4 lb)	II-4; III-4,5
Chemicals, household:		
alcohol, rubbing	1.5 qt (1.5 liter)	I-3,5
ammonia, household variety	30 ml (1 oz)	I-3
baking soda (sodium bicarbonate)	small box	III-1,4

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
camphor	1 cake	V-2
cornstarch	1 box	II-5
cream of tartar (potassium bitartrate)	1 small box	III-1,3,4
food coloring:		
blue	1-2 oz	IV-4,6; V-1
green (optional)	1/8 oz	V-1
yellow	1/8 oz	IV-4; V-1
gelatin, unflavored	2-3 packets (7 g/pkg)	V-1
glycerin	1/2 cup	II-2
iodine, 2% tincture	1 oz (30 ml)	II-5
mineral oil	1/2 cup	II-2
sugar (sucrose)	1 lb (450 g)	I-2,3; II-1; III-1
table salt (sodium chloride) several varieties, include free-flowing, kosher style, halite deicer, or chemically pure	450 g (1 lb) at most	II-1; III-1, 4,5
vaseline, white (petroleum jelly)	125 g (4 oz)	I-4
vinegar, white (acetic acid) household variety	500 ml (1 pint)	I-3; III-2,5
Clay, plasticene model	supply	II-3; VI-2
Clock, or timer, with sweep second hand	1	IV-3,7; V-4
Cloth:		
cotton, 2.5 cm by 5 cm (1 in. by 2 in.)	7 pieces	I-4

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
carpeting or rug, 60 cm by 60 cm (2 ft by 2 ft)	1 piece	VI-1
Containers:		
coffee cans, 1 lb size, with plastic lid	16	I-1
gallon (4 liters) or 4-1 liter (1 qt)	1	IV-6
polyfoam, 3 liters (3 qt) with lid	6	II-1,2,4; III-1,2,3,4,5; IV-1,2,3
transparent, 1 liter capacity (1 qt)	2	IV-4
wide, squat, for chemical supplies, e.g., a cottage cheese container	at least 9	II-1,2,3,4; III-1,2,3,4,5; IV-2
Copper:		
pieces, e.g., wire, penny, etc.	several	III-4
shiny objects, e.g., pots, new pennies	several	III-2
wire, 18 gauge	72 in. (200 cm)	III-5
Corks:		
to fit 13 mm by 100 mm test tube	60 plus	II-2; III-2; V-1
to fit 18 mm by 150 mm test tube	4	V-1
Cups:		
plastic or waxed paper, about 30 ml (1 oz)	150-250	I-1,2,4; II-5; III-1,2,3,4,5; IV-1,2,4; V-1

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
transparent plastic, "old-fashioned" shape, 120 to 240 ml (4-8 oz) capacity (glass slides can substitute for some)	250	II-5; III-1, 3,5; IV-4,5,6
plastic, 150 ml (5 oz) capacity, to fit into polyfoam cup	15	IV-3
polyfoam, 180 to 240 ml (6-8 oz)	60-200	I-1,3; II-1, 2,4; III-2,3; IV-1,2,3; V-2,5
measuring	2 or more	I-4; V-1
Dishes:		
for discarded matches, glass or porcelain	15	III-4
shallow, or petri type, glass or plastic, 10 cm (4 in.) in diameter	1 (4 more optional)	II-1,3; V-2
Fan, electric	1	I-4
Funnel, about 15 cm (6 in.) in diameter	10	I-5; II-5; IV-4
Geiger counter (or prepared tape of background count)	1	V-4
Glass, tall, as test tube rack	1	V-1
Glass rod, 10 cm long (4 in.) (optional)	8	IV-7
Graphite, powdered lubricant	1 tube	VI-3
Hammer, or heavy object	1	V-2
Heat sources:		
candle, short squat variety	30 or more	II-1,3; IV-7
hot plate	1	I-3; IV-2

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
Sterno	40 cans	II-2,4,5; III-4,5
Hexstat (optional), see page 459 for ordering	2-3 at least	V-3
Ice:		
cubes	95	IV-1,7
chips	supply	II-1
Jars:		
babyfood jars, 120-ml (4-oz), or substitute	68 (approx.)	I-2,3,4,5
to serve as test tube rack, e.g., babyfood jar, mug. etc.	35	II-2,4,5; III-2,3,4,5; V-1
1/2 liter (1 pt) capacity	2	I-2; II-5
tall narrow glass with lid, e.g., olive jar	8	I-1,3
wide mouth with lid, mouth to be at least 3 in. (7.5 cm) wide	30	I-3
1-liter (1 qt) with lid	1	I-3; II-5
3-liter (3 qt) with lid	2	I-3
Knives, paring	10	I-5
Labels	15	I-3
Lamp, gooseneck, or equivalent	10	I-5
Line, nylon fishing	15 meters (about 45 feet)	VI-2,4,5
Magnets	several	III-2
Magnifying glasses, (e.g., American Science and Engineering No. 2400, 126X)	32	I-1,5; II-1,3,4; III-1,2,3

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
Marbles:		
same size and color	30	II-1
different than those above	5 or more	II-3; V-2
Matches, safety	6 boxes (approx.)	II-1,2,4; III-4
Mealworms (available from pet and aquarium supply stores)	100 (approx.)	I-3
Medicine droppers	36	I-2,3; II-2,3, 4,5; III-1; V-1
Microscopes, compound:		
40X	8-10	I-5; II-3; III-1
100X or higher	1 or more	I-2
Microscope slides	30 or more	I-2,5; III-1,3
Miscrscope slide covers	60 or more	I-2
Nails:		
aluminum, 10 cm (4 in.) long (optional)	8	IV-7
iron, bright, common variety 5 cm (2 in.) long	150 or more	III-2,3,4,5
iron, 10 cm (4 in.) long	15	IV-7; VI-2
2.5 cm (1 in.) long	30	V-2
Paint, blue	1 aerosol can	IV-5
Pans:		
aluminum, 10 cm (4 in.) in diameter or equivalent	16	I-1,4,5
aluminum, 20 cm (8 in.) in diameter or equivalent	6	I-4

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
aluminum, pie size	1	V-2
sauce, 2 liters (2 qt) capacity	1	I-3; II-5; IV-2
shallow, cookie sheet shape or tray	12	I-4
Paper:		
construction, black, 8-1/2 in. by 11 in. (21 cm by 27 cm)	10 sheets	I-5
construction, colored or plastic	1 or more sheets	V-2
filter	2 sheets	IV-4; II-5
graph, 2 sq/cm (4/in.)	supply (at least 300 sheets)	IV-1,2,3,5,7; V-2,4; VI-1
newspaper, double sheets	25	I-1,5
towels	supply	I-1,2; II-4,5; III-2,5; IV-1,7
scrap, white	supply	I-1; II-2,3; III-2,4; IV-2,5
wrapping, 60 cm by 180 cm (2 ft by 6 ft)	1 sheet	VI-1
Paper clips, No. 1, tinned steel variety	100 (approx.) or more	III-4,5; IV-5
Pencils:		
(or felt tip pen)	30	IV-1,2; V-2
blue, or crayons	30	IV-3,6; V-2,3
red, or crayons	30	IV-3,7; V-2,3
two more colors than above	30 of each	IV-3; V-2,3
glass marking	16	III-1; IV-5,6

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
unsharpened, with eraser	60	VI-1,2
Pens, felt marking, different colors including black	1 set	VI-1
Perishables:		
fresh fruits, e.g., tomato, bananas, apples, grapes, plums, apricots	several	I-3
fresh vegetables (not green) e.g., carrots, potatoes	several	I-3
housefly pupae (optional, see page 459)		V-5
red cabbage	1 medium	I-3
Pins:		
bobby	30	V-2
clothes	30 or more	IV-4
Pitchers, with pouring spout as a teapot, about 1/2 liter (1-pt) capacity	4 or more	I-2,3; IV-4
Plants and seeds (other than perishables):		
beans, navy pea (dried)	1 lb	IV-5
geranium, potted, about 30 cm (12 in.) tall	8	I-1,4
flower buds	several	I-3
corn seeds	1 pkg (1 oz)	I-1
radish seeds	1 pkg (about 50)	I-3
Plastic:		
transparent discs (or squares) about 3 cm in diameter, four different colors	12-18 of each color	III-3

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
transparent red discs (or squares)	120	V-5
transparent clear discs (or squares)	90	V-5
wrap	2-3 rolls	I-3; II-1,2, 3,4; III-1,4; V-2
Projectors:		
micro (optional)	1	III-1,2,5
overhead (optional)	1	III-1,2,3,5
Pump, bicycle, with hose	1	I-3
Rubber bands, small	40	IV-7; VI-1
Rulers:		
30 cm (12 in.) with hole near one end	45	I-4,5; VI-1, 2,3,4,5
1 meter (3 ft) (1 meter or yardstick)	15	VI-5
Rusty objects	several	III-2
Scissors	15	I-1,4,5; III-2; IV-4,7; V-2,3
Screens, wire		
4-in. mesh, 15 cm by 15 cm (6 in. by 6 in.)	8	I-1
10-in. mesh, 15 cm by 15 cm (6 in. by 6 in.)	8	I-1
14-in. mesh, 12 cm by 12 cm (5 in. by 5 in.)	10	I-5
18-in. mesh, 15 cm by 15 cm (6 in. by 6 in.)	8	I-1

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
Soils:		
topsoil	8 liters (8 qts)	I-1
subsoil	8 liters (8 qts)	I-1
Spoons:		
tablespoon	15	II-5; IV-6
teaspoon	16	I-2,3; III-4,6
1/2 teaspoon (plastic picnic variety)	several	III-2
Sprinkler bulb	1-8	I-1
Steel wool, fine	supply about 15 balls	III-2,5
Straws, drinking	30	I-3
String, light laundry variety	2 balls	I-4; II-2; III-2; VI-3
Tape:		
plastic or cellophane	4 rolls (approx.)	I-4,5; III-4; IV-7; V-2,3
masking	1 roll	III-4; VI-1, 3,5
masking, double-sided	supply	II-1
Test tubes, heat resistant:		
13 mm by 100 mm (5/8 in. by 4 in.)	75 or more	I-4; II-2,4,5; III-2,3,5; V-1
18 mm by 150 mm (3/4 in. by 6 in.)	4	V-1
Test tube holders, metal	30	II-1,2,4,5; III-4

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
Thermometers:		
-20°C to +50°C, plastic backed, e.g., Macalaster No. 2662	34 or more	I-1,4,5; II-4, 5; IV-1,2,3,7
laboratory style, -10°C to +110°C	1	II-5; IV-2
Tubing (dialysis) cellophane 3 cm wide (1-1/8 in.)	600 cm (20 ft)	IV-4
Trowel, hand	1	I-5
Tweezers (optional)		III-1
Wood:		
narrow strips, as dispensers; e.g., popsicle sticks, flattened straws	40	II-1,2,5; III-1; IV-2
stirrers, e.g., popsicle sticks, beverage stirrers, etc.	110	I-2,3,5; IV-1
toothpicks	2 boxes	I-5; II-3; III-1,2,3
block, 5 cm by 5 cm by 10 cm (2 in. by 2 in. by 4 in.) or substitute	15	VI-4
Woodland litter	10 gals	I-5
Worksheets:		
Worksheet I-1	8	I-1
Worksheet I-2	30	I-4
Worksheet III-1	15	III-4
Worksheet IV-1	15	IV-3
Worksheet IV-2	30	IV-5
Worksheet IV-3	30	IV-5
Worksheet IV-4	30	IV-6

ITEMS	QUANTITY	MINISEQUENCE AND ACTIVITY
Worksheet IV-5	8 or more	IV-7
Worksheet V-1	60	V-2,3
Worksheet V-2	15	V-2
Worksheet V-3	30	V-3
Worksheet V-4	30	V-4
Worksheet V-5	15	V-5
Worksheet V-6	15	V-5
Worksheet V-7 (optional)	15	V-5
Worksheet VI-1	30	VI-3
Worksheet VI-2	30	VI-3
Worksheet VI-3	30	VI-4
Yeast, "active dry"	40 pkgs. (7 g/pkg)	I-2,3

SCIENTIFIC SUPPLY HOUSES

American Science and Engineering (A.S. and E.)
20 Overland Street
Boston, Massachusetts 02215
(magnifying glasses and
thermometers)

Central Scientific Co. (Cenco)
2600 South Kostner Avenue
Chicago, Illinois 60613
(school science supplies and
Ohaus equipment)

Continental Biological Labs
448 North Halsted
Chicago, Illinois 60622
(housefly pupae)

Damon Educational Division
80 Wilson Way
Westwood, Massachusetts 02090
(-20°C to +50°C thermometers)

Educational Science Consultants
P.O. Box 1674
San Leandro, California 94577
(housefly kit and book)

Fisher Scientific Co.
52 Fadem Road
Springfield, New Jersey 07081
(chemicals, and other
laboratory supplies)

Greiner Scientific Corporation
22 North Moore Street
New York, New York 10004
(cellophane tubing and
laboratory supplies)

Harcourt Brace Jovanovich, Inc.
737 Third Avenue
New York, N.Y. 10017
(Hexstats)

Learning Resource Center, Inc.
10655 S.W. Greenburg Road
Portland, Oregon 97223
(heating stands and other
school science equipment)
(This company was formerly
known as OMSI.)

Macalaster Scientific Corp.
Division of Raytheon Educational Company
Route 111 & Everett Turnpike
Nashua, New Hampshire 03060
(-20°C to +50°C thermometers)

Scientific Glass Apparatus Co.
725 Broad Street
Bloomfield, New Jersey 07003
(funnels, filter paper and
other laboratory supplies)

Science Kit, Inc.
Tonawanda, New York 14150
(school science supplies)

Selective Educational Equipment
3 Bridge Street
Newton, Massachusetts 02195
(medicine droppers, and
magnifiers)

Sigma Scientific, Inc.
P.O. Box 1302
Gainesville, Florida 32601
(school science supplies)

Worksheet Pages for Duplication

WORKSHEET I-1 Name:

DAY	OBSERVATIONS OF PLANTS	
	IN TOPSOIL	IN SUBSOIL

WORKSHEET I-2 Name:

Data on Relative Humidity

TIME AND PLACE	DRY-BULB TEMP.	WET-BULB TEMP.	TEMP. DIFF.	REL. HUM.

475

CONVERSION OF THERMOMETER READINGS INTO RELATIVE HUMIDITY (%)

TEMPERATURE OF DRY-BULB IN °C.	DIFFERENCE BETWEEN WET-BULB AND DRY-BULB IN °C.								
	1	2	3	4	5	6	7	8	9
+9	88	76	65	53	42	32	22	12	
+12	89	78	68	58	48	28	30	21	12
+15	90	80	71	62	53	44	36	28	20
+18	90	82	73	65	57	49	42	35	27
+21	91	83	75	67	60	53	46	39	32
+24	92	85	77	70	63	56	49	43	37
+27	93	86	79	72	65	59	53	47	41
+30	93	86	79	73	67	61	55	50	44

WORKSHEET III-1 Name:

SUBSTANCE NUMBER	COLOR OF FLAME	UNIT IN COMMON WITH	CHEMICAL NAME	
			Unit Responsible	Partner

WORKSHEET IV-1 Name:

Situation_____

TIME (minutes)	TEMPERATURE (°C)	
	outer-cup (colder sample)	inner cup (hotter sample)
0		
1/2		
1		
1-1/2		
2		
2-1/2		
3		
3-1/2		
4		
4-1/2		
5		

Colder Sample:

BEFORE
Temp._____°C
Volume_____
h.e.u._____

AFTER
Temp._____°C
Volume_____
h.e.u._____

Hotter Sample:

BEFORE
Temp._____°C
Volume_____
h.e.u._____

AFTER
Temp._____°C
Volume_____
h.e.u._____

WORKSHEET IV-2 Name:

NUMBER OF EXCHANGES OF FOUR BEANS	NUMBER OF BLUE BEANS IN	
	CUP 1	CUP 2

WORKSHEET IV-3

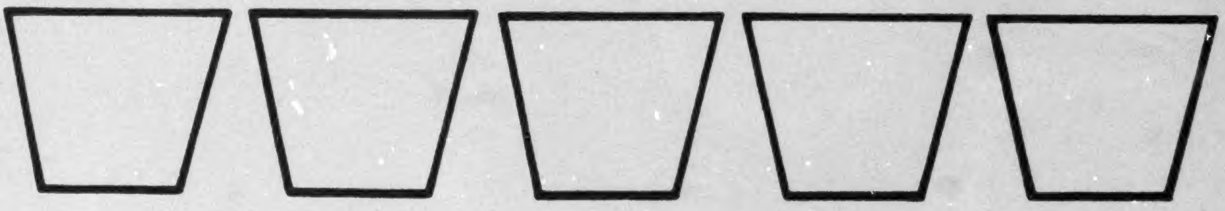
Name:

NUMBER OF BLUE BEANS IN CUP 1						
NUMBER OF EX-CHANGES OF FOUR BEANS	DATA TAKEN BY:					AVERAGE

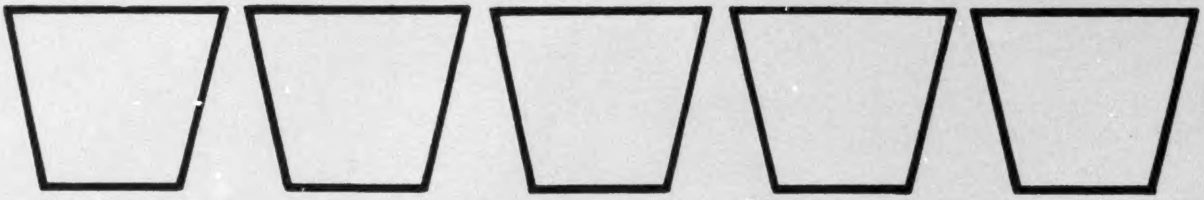
NUMBER OF BLUE BEANS IN CUP 2						
NUMBER OF EX-CHANGES OF FOUR BEANS	DATA TAKEN BY:					AVERAGE

WORKSHEET IV-4 Name:

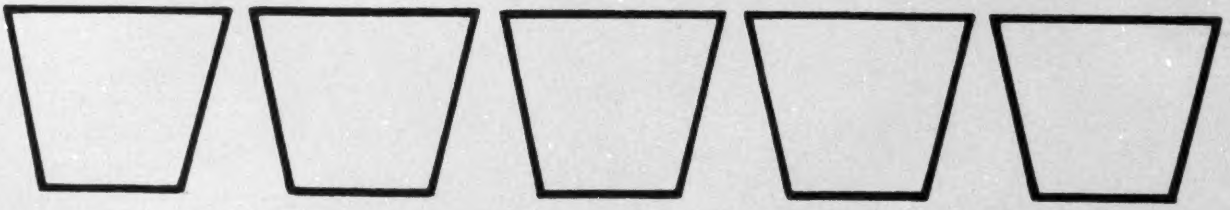
START:



AFTER ____ SERIES OF EXCHANGES:



FINISH:

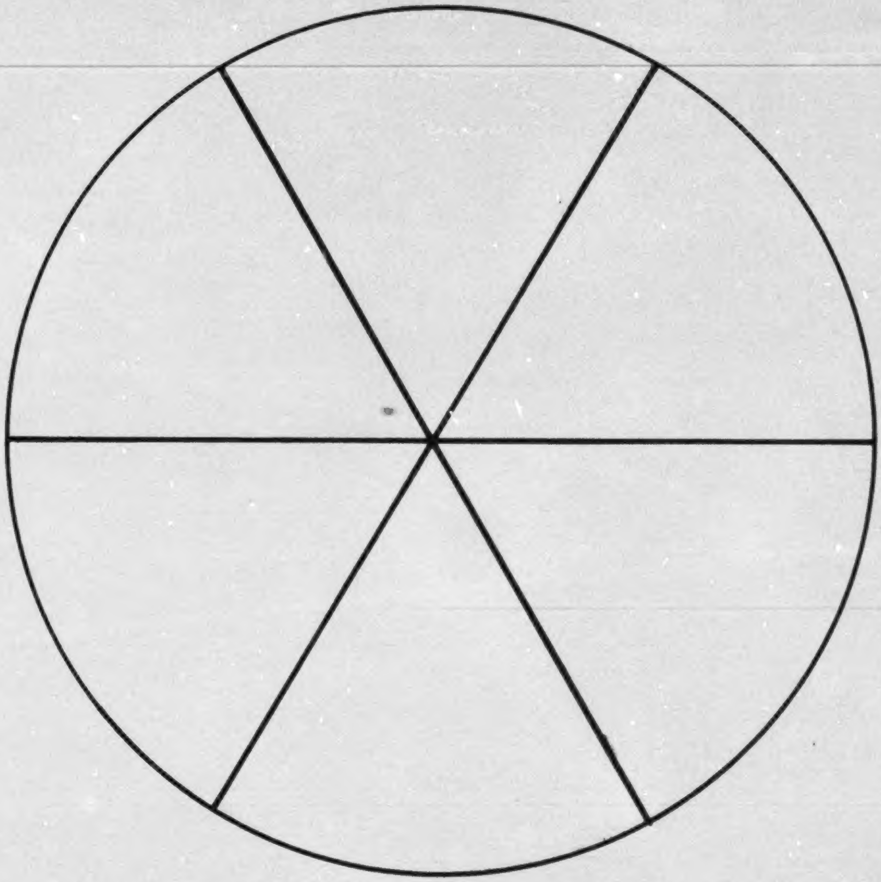


WORKSHEET IV-5 Name:

TIME (min.)	TEMPERATURE (°C)			
	Thermometer 1	Thermometer 2	Thermometer 3	Thermometer 4
0				
1/2				
1				
1-1/2				
2				
2-1/2				
3				
3-1/2				
4				
4-1/2				
5				
5-1/2				
6				
6-1/2				
7				

DESCRIPTION OF EXPERIMENT: ______________________________

WORKSHEET V-1



WORKSHEET V-2

Names:

		15
		14
		13
		12
		11
		10
		9
		8
		7
		6
		5
		4
		3
		2
		1
		0
		-1
		-2
		-3
		-4
		-5
		-6
		-7
		-8
		-9
		-10
		-11
		-12
		-13
		-14
		-15

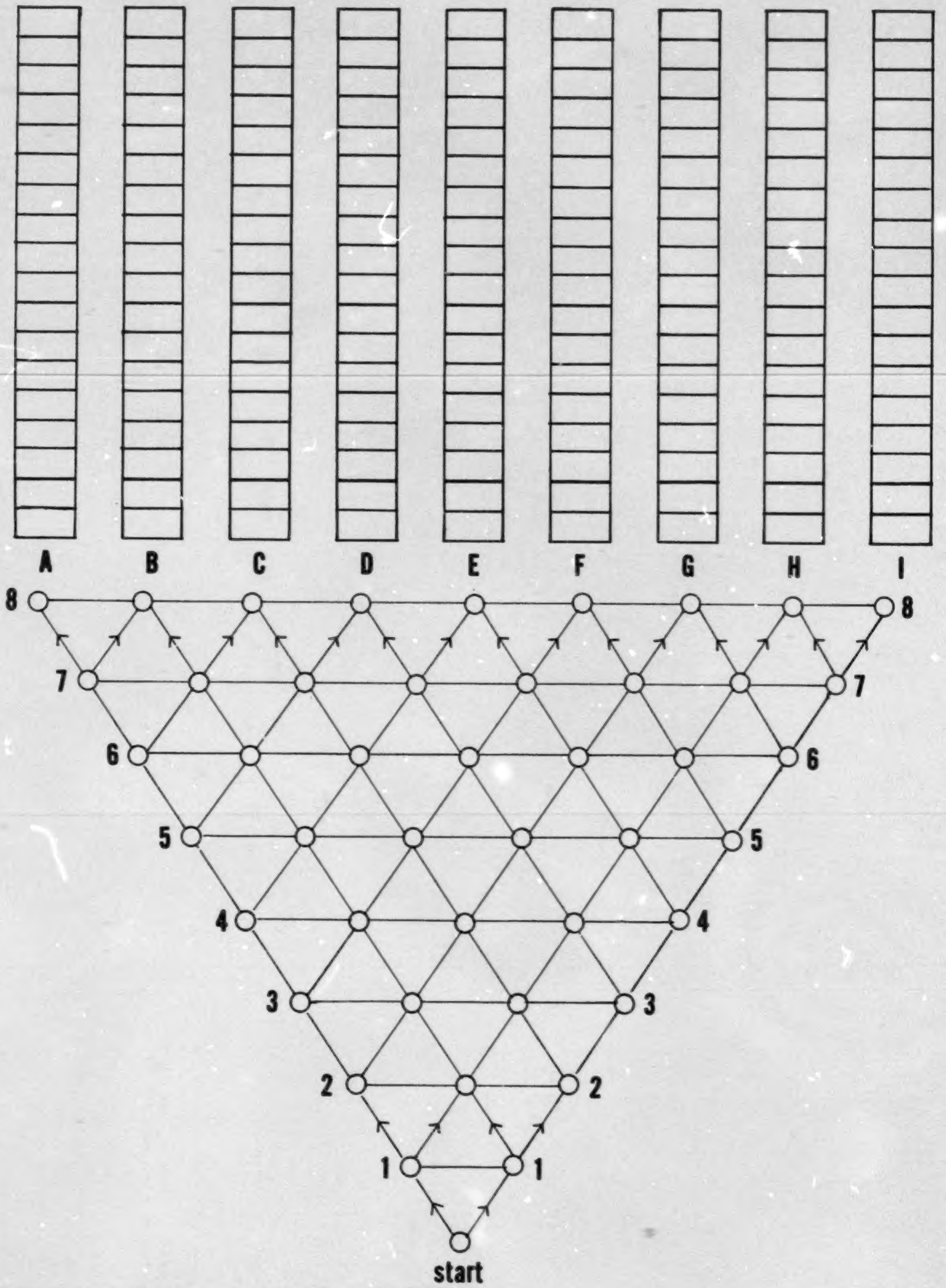
RECORD AND TALLY:

	Space Occupied by			Spread Between U and D
	M	U	D	
After 10 Steps				
20				
30				
40				
50				

CONCLUSIONS:

WORKSHEET V-3

Name:


A
B
C
D
E
F
G
H
I
8
8
7
7
6
6
5
5
4
4
3
3
2
2
1
1
start

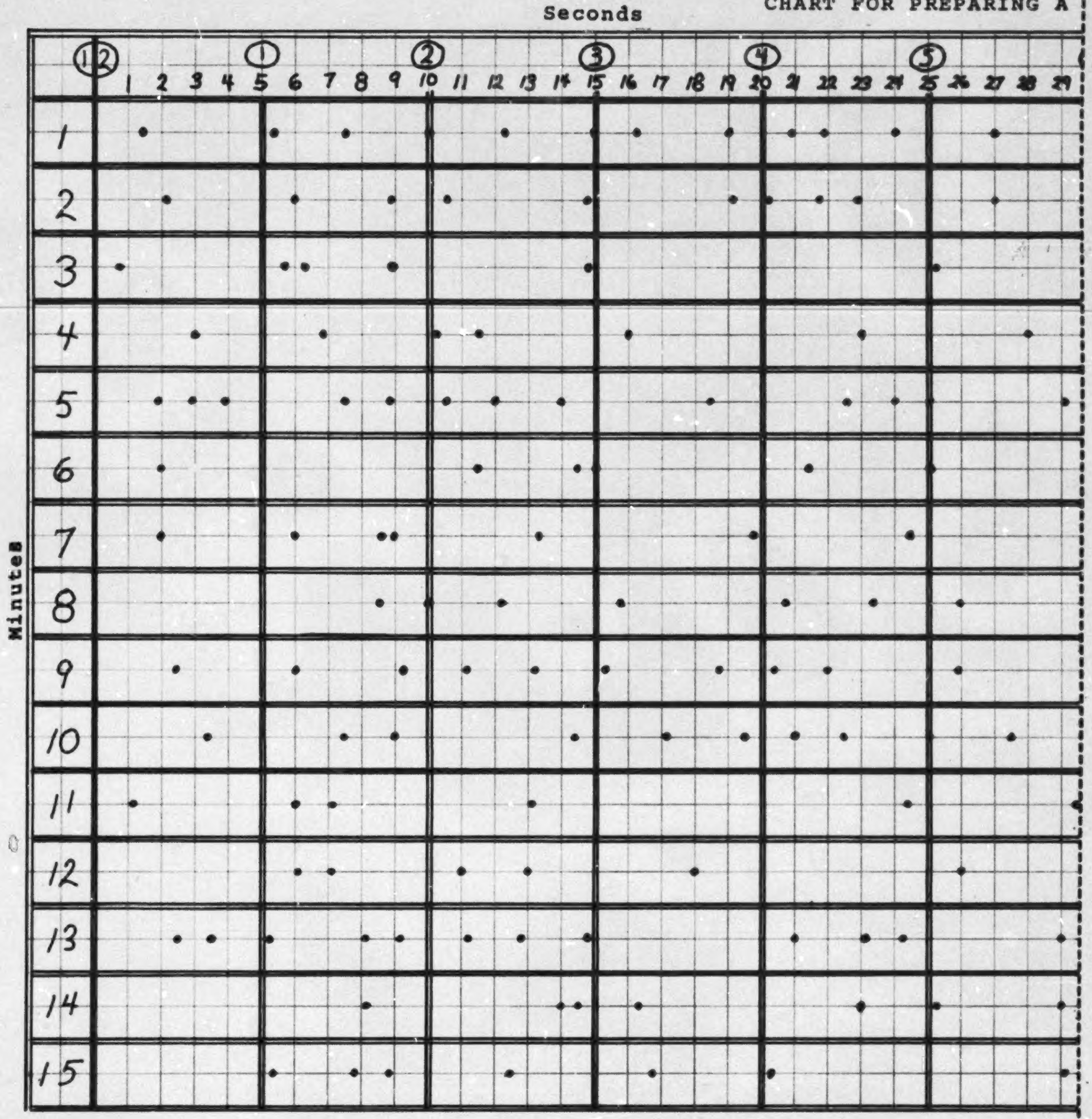
WORKSHEET V-4

Name:

TRIAL	TIME INTERVAL (sec)	NUMBER OF COUNTS	MULTIPLY BY	CALCULATED COUNTS/MIN.
1	5		12	
2	5			
3	5			
4	5			
5	5			
6	5			
7	5			
8	5			
9	5			
10	5			
11	5			
12	5			
	60 sec=1 min.			
1	10		6	
2	10			
3	10			
4	10			
5	10			
6	10			
	60 sec=1 min.			
1	20		3	
2	20			
3	20			
4	20			
5	20			
6	20			
	120 sec=2 min.			
1	60		1	
2	60			
3	60			
4	60			
5	60			
6	60			
	300 sec=5 min.			
1	120		1/2	
2	120			
3	120			
	360 sec=6 min.			

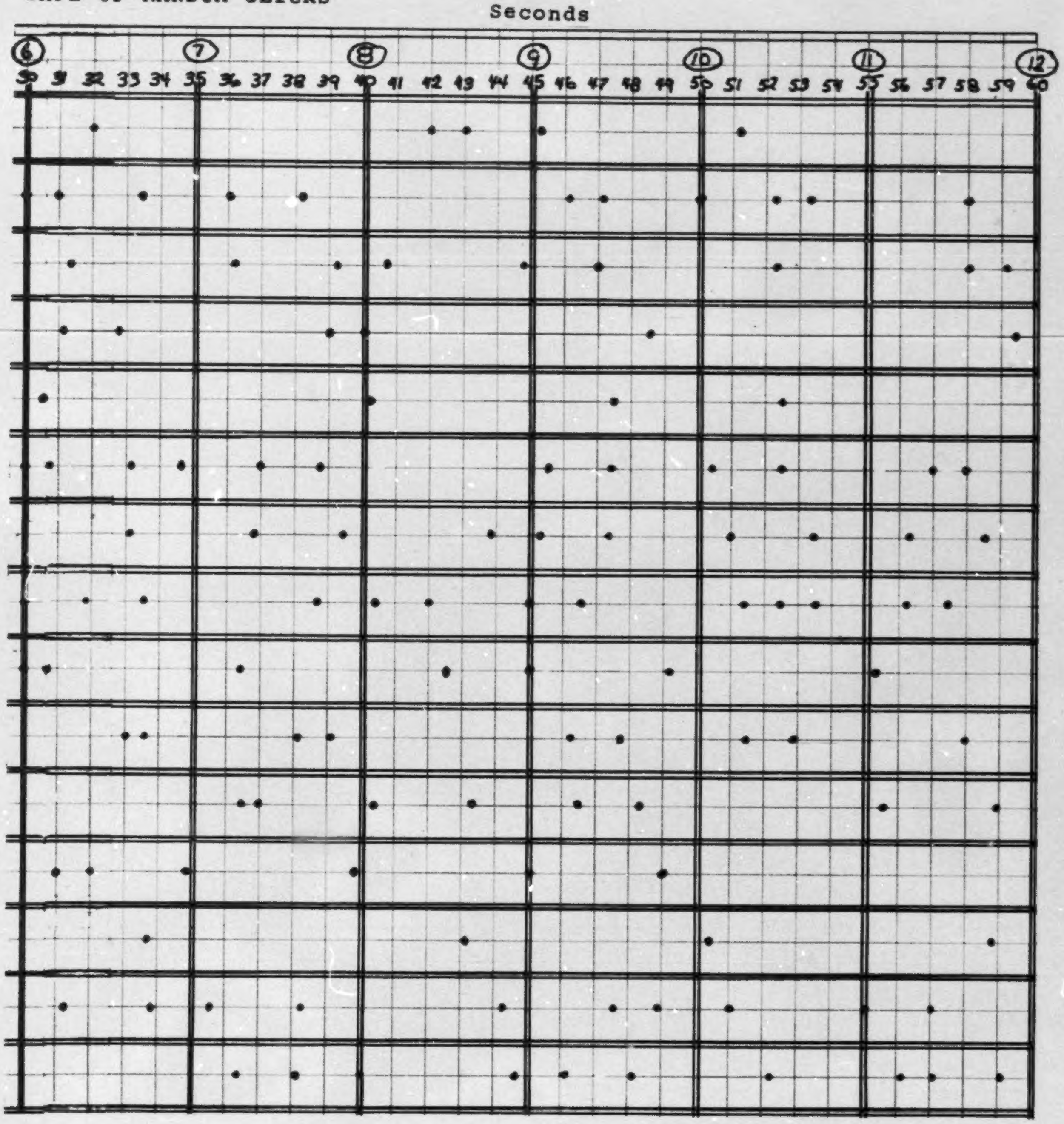
AVERAGE COUNTS/MINUTE = $\frac{\text{TOTAL COUNTS FOR ALL TRIALS}}{\text{TIME IN MIN. FOR ALL TRIALS}}$ =

CHART FOR PREPARING A



To use this chart, first tear out this page and page 491. Then cut along the dotted line and either tape or paste the two pages together so that they can be read from left to right with no break between.

TAPE OF RANDOM CLICKS



WORKSHEET V-5 Name:

Table 1: A FIRST GENERATION POPULATION OF HOUSE FLIES

	Red Eyes	White Eyes	Total
Male	50		50
Female			
Total	100		100

Table 2: A SECOND GENERATION POPULATION OF HOUSE FLIES

	Red Eyes	White Eyes	Total
Male	3,750		5,000
Female			
Total	7,500	2,500	

Table 2a: A RANDOM SAMPLE OF 100 FLIES FROM THE SECOND GENERATION

	Red Eyes	White Eyes	Total
Male	34	14	48
Female	36	16	52
Total	70	30	100

Table 2b: A SECOND RANDOM SAMPLE OF 100 FLIES

	Red Eyes	White Eyes	Total
Male		13	51
Female			
Total	74		100

Table 2c: A RANDOM SAMPLE OF 20 FLIES FROM THE SECOND GENERATION

	Red Eyes	White Eyes	Total
Male	7		10
Female			
Total	13		20

Table 2d: A SECOND RANDOM SAMPLE OF 20 FLIES

	Red Eyes	White Eyes	Total
Male			12
Female			
Total	18		20

WORKSHEET V-6 Name:

SELECTION	FACTOR INHERITED FROM	
	Female Parent	Male Parent
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

SELECTION	FACTOR INHERITED FROM	
	Female Parent	Male Parent
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

KINDS OF COMBINATIONS OF FACTORS	NUMBER OF EACH KIND OF COMBINATION	EYE COLOR OF THE COMBINATION

WORKSHEET V-7 Name:

Table 3: A SELECTED SAMPLE OF 100 WHITE-EYED FLIES FROM THE SECOND GENERATION

	White Eyes
Male	
Female	50
Total	100

Table 4: OFFSPRING OF SELECTED WHITE-EYED SAMPLE

	Red Eyes	White Eyes	Total
Male			5,000
Female		5,000	
Total		10,000	10,000

Table 5: A SELECTED SAMPLE OF 100 RED-EYED FLIES FROM THE SECOND GENERATION

	Red Eyes
Male	50
Female	
Total	100

Table 6: OFFSPRING OF SELECTED RED-EYED SAMPLE

	Red Eyes	White Eyes	Total
Male		556	5,000
Female			
Total	8,889	1,111	10,000

WORKSHEET VI-1

Name:

	STRAIGHT UP	ALONG THE RAMP (1)	ALONG THE RAMP (2)
FORCE NEEDED TO MOVE BOOK			
DISTANCE MOVED FROM FLOOR TO TOP OF RAMP			
WORK DONE (F X D)			

WORKSHEET VI-2 Name:

	STRAIGHT UP	ALONG THE RAMP
FORCE NEEDED TO MOVE METAL BALL		
DISTANCE MOVED FROM FLOOR TO TOP OF RAMP		
WORK DONE (F X D)		

WORKSHEET VI-3

Name:

TRIAL	HEIGHT OF BOB BEFORE RELEASED	RELATIVE POTENTIAL ENERGY BEFORE RELEASED	RELATIVE SPEED OR KINETIC ENERGY AT BOTTOM OF SWING	AVERAGE DISTANCE BLOCK MOVED